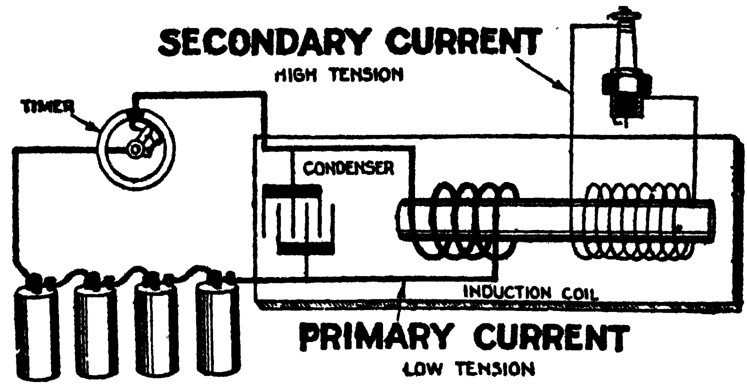

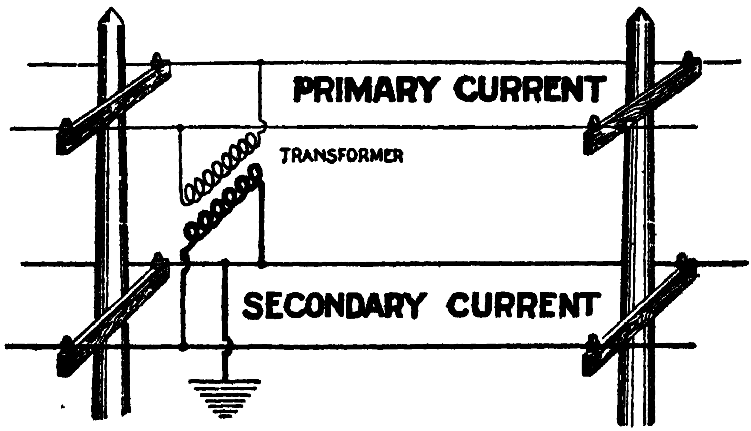

Primary and Secondary Circuits

Ignition and lighting circuits illustrating *primary* and *secondary* current, *high tension* and *low tension*. It will be seen from the illustrations that *careful distinction* must be made between *primary* and *secondary* current.

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VOL. 1

FOR ENGINEERS, ELECTRICIANS
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Presenting in simplest, concise form the fundamental principles, rules and applications of applied electricity.
Fully illustrated with diagrams and sketches.
Including calculations and tables for ready reference.
Helpful questions and answers. Trial tests for practice, study and review.
Based on the best knowledge and experience of applied electricity.

by FRANK D. GRAHAM, B.S., M.S., M.E., E.E.

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Printed by K. L. Bhargava at K. L. Bhargava & Co., Impression House, G. D. Ambekar Marg, Bombay 31 and published by R. J. Taraporevala for D. B. Taraporevala Sons & Co. Private Ltd., 210, Dr. Dadabhai Naoroji Road, Bombay 1.

Foreword

This series is dedicated to Electrical Progress—to all who have helped and those who may in the coming years help to bring further under human control and service to humanity this mighty force of the Creator.

The Electrical Age has opened new problems to all connected with modern industry, making a thorough working knowledge of the fundamental principles of applied electricity necessary.

The author, following the popular appeal for practical knowledge, has prepared this progressive series for the electrical worker and student; for all who are seeking electrical knowledge as a life profession; and for those who find that there is a gap in their training and knowledge of Electricity.

Simplicity is the keynote throughout this series. From this progressive step-by-step method of instruction and explanation, the reader can easily gain a thorough knowledge of modern electrical practice in line with the best information and experience.

The author and publishers here gratefully acknowledge the hearty and generous help and co-operation of all those who have aided in developing this helpful series of Educators.

The series will speak for itself and "those who run may read."

The Publishers.

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How to Use This Book

Finder

IMPORTANT

To quickly and easily find information on any subject, read over the general chapter headings as shown in the large type—this brings the reader's attention to the general classification of information in this book.

Each chapter is progressive, so that if the reader will use the outline following each general chapter heading, he will readily come to the information desired and the page on which to find it.

Get the habit of using this Index—it will quickly reveal a vast mine of valuable information.

"An hour with a book would have brought to your mind,
The secret that took the whole year to find;
The facts that you learned at enormous expense,
Were all on a library shelf to commence."

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SIGNS AND SYMBOLS

The following signs, symbols and abbreviations are almost universally employed in descriptive and technical works on electrical subjects.

Although, in the arrangement of the Guides, the direct current and alternating current matter has been kept separate, it is perhaps advisable in the case of signs and symbols, to combine those relating to the alternating current with the direct current and other symbols, making a single table, rather than have them scattered throughout the work.

1. Fundamental.

l, Length. cm. = centimeter; in., or ″ = inch, ft. or ′ = foot.
M. Mass. gr. = mass of 1 gramme; kg. = 1 kilogramme.
T, *t*, Time. *s* = second.

2. Derived Geometric.

S, *s*, Surface.
E, Volume.
α, β, Angle.

3. Derived Mechanical.

v, Velocity.
Angular velocity.
m, Momentum.
a, Acceleration.
g, Acceleration due to gravity = 32.2 feet per second.
F, *f*, Force.
W, Work.
P, Power.
δ, Dyne.
e, Ergs.
ft. lb., Foot pound.
H.P., h.p.; horse power.
I.H.P., Indicated horse power.
B.H.P., Brake horse power.
E.H.P., Electrical horse power.
J, Joule's equivalent.
p, Pressure.
K, Moment of inertia.

4. Derived Electrostatic.

e, Pressure difference.
i, Current.
r, Resistance.
q, Quantity.
c, Capacity.
sc, Specific inductive capacity.

5. Derived Magnetic.

m, Strength of pole.
$\mathcal{J}$, Intensity of magnetization.
$\mathcal{M}$, Magnetic moment.
$\mathcal{H}$, Horizontal intensity of earth's magnetism.
$\mathcal{H}$, Field intensity.
Φ, Magnetic flux.
$\mathcal{B}$, Magnetic flux density or magnetic induction.
$\mathcal{H}$, Magnetizing force.
$\mathcal{F}$, Magnetomotive force.
$\mathcal{R}$, Reluctance, magnetic resistance.
μ. Magnetic permeability.
κ, Magnetic susceptibility.
ν, Reluctivity (specific magnetic resistance).

6. Derived Electromagnetic.

R, Resistance, ohm.
O, do, megohm.
E, Volt, pressure.
- E_{im} Impressed pressure.
- E_a; E_o Active pressure; ohmic drop.
- E_v Virtual pressure.
- E_{max} Maximum pressure.
- E_{av} Average pressure.
- E_{ef} Effective pressure.
- E_l Inductance pressure.
- E_c Capacity pressure.

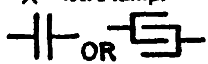
U, Difference of pressure, volt.
I, Intensity of current, ampere.
- I_{im} Impressed current.
- I_a Active current.
- I_v Virtual current.
- I_{max} Maximum current.
- I_{av} Average current.
- I_{ef} Effective current.

Q, Quantity of electricity, ampere hour; coulomb.
C, Capacity, farad.
W, Electric energy, watt hour; Joule.
P, Electric power, watt; kilowatt.
ρ, Resistivity (specific resistance) ohm centimeter.
G, Conductance, mho.
γ, Conductivity (specific conductivity).
Y, Admittance, mho.
Z, Impedance, ohm.
X, Reactance, ohm.
- X_l Inductance reactance.
- X_c Capacity reactance.

B, Susceptance, mho.
L, Inductance (coefficient of Induction), henry.
v, Ratio of electro-magnetic to electrostatic unit of quantity $= 3 \times 10^{10}$ centimeters per second approximately.

7. Symbols in general use.

D, Diameter.
r, Radius.
t, Temperature.
θ, Deflection of galvanometer needle.
N, n, Number of anything.
π, Circumference ÷ diameter = 3.141592.
ω, $2\pi f = 6.2831 \times$ frequency, in alternating current.
~ f, Frequency, periodicity, cycles per second.
ϕ Phase angle.
G, Galvanometer.
S, Shunt.
N, n, North pole of a magnet.
S, s, South pole of a magnet.
A.C. Alternating current.
D.C. Direct current.
P.D. Pressure difference.
P.F. Power factor.
C.G.S. Centimeter, gramme, Second system.
B.&S. Brown & Sharpe wire gauge.
B.W.G. Birmingham wire gauge.
R.p.m. Revolutions per minute.
C.P. Candle power.
—o— Incandescent lamp.
—×—. Arc lamp.

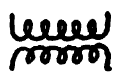

Condenser.

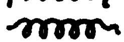

Battery of cells.


Dynamo, or direct current motor.

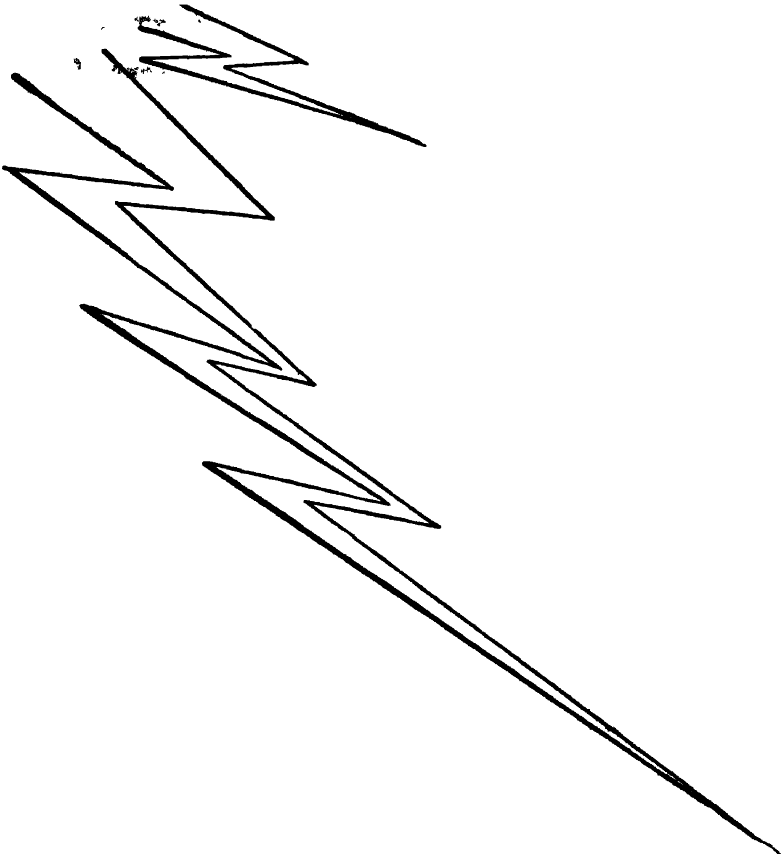

Alternator, or alternating current motor.


Converter.


Static transformer..


Inductive resistance.


Non-inductive resistance



CHAPTER 1

Electricity

Nature and Source of Electricity.—What is electricity? This is a question that is frequently asked, but has not yet been satisfactorily answered. It may be defined ***a force, subject to control under well known laws.***

The true nature of electricity has not yet been discovered. Many think it a quality inherent in nearly all the substances, and accompanied by a peculiar movement or arrangement of the molecules. Some assume that the phenomena of electricity are due to a peculiar state of strain or tension in the ether which is present everywhere, even in and between the atoms of the most solid bodies. If the latter theory be the true one, and if the atmosphere of the earth be surrounded by the same ether, it may be possible to establish these assumptions as facts.

The most modern supposition regarding this matter, by Maxwell, is that light itself is founded on electricity, and that *light waves* are merely *electro-magnetic waves.*

Electricity is sometimes classified according to its motion, as:

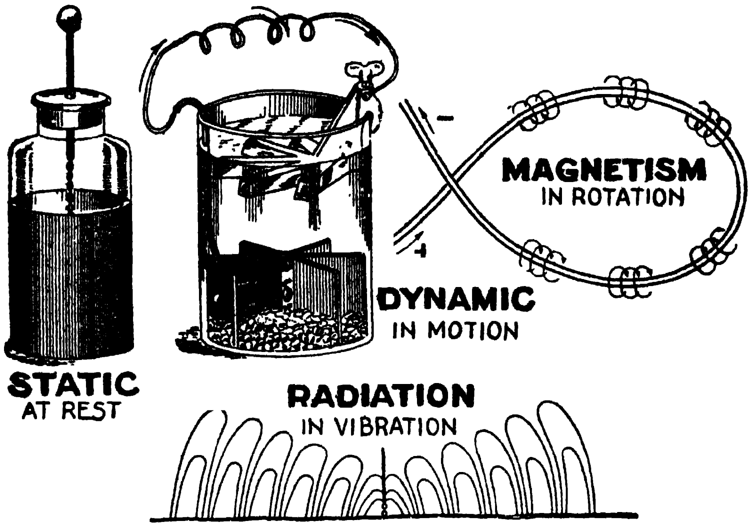
1. Static electricity, or electricity *at rest,*
2. Current electricity, or electricity *in motion;*
3. Magnetism, or electricity *in rotation;*
4. Radio electricity, or electricity *in vibration* (radiation).

Other useful divisions are:

1. Positive;

2. Negative electricity;
3. Dynamic electricity.

Static Electricity.—This is a term employed to define *electricity produced by friction.* It is properly employed in the sense of a static charge which shows itself by the attraction or repulsion between charged bodies.



Figs. 1 to 4.—The four kinds of electricity. 1, static electricity; 2, dynamic electricity in lineal motion; 3, magnetism electricity in rotation; 4, radio electricity in vibration.

When static electricity is discharged, it causes more or less of a current which shows itself by the passage of sparks or a brush discharge; by a peculiar prickling sensation; by a peculiar smell due to its chemical effects; by heating the air or other substances in its path; and sometimes in other ways.

Current Electricity.—This may be defined as *the quantity of electricity which passes through a conductor in a given time—or, electricity in the act of being discharged, or electricity in motion.*

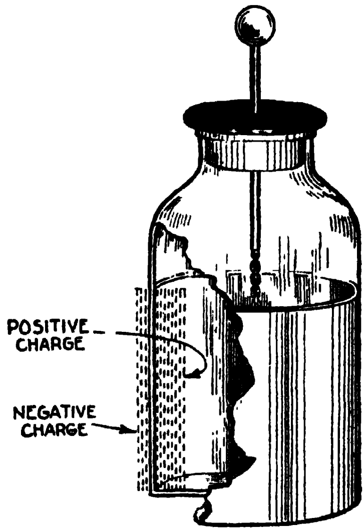


FIG. 5.—Charged Leyden jar illustrating static electricity.

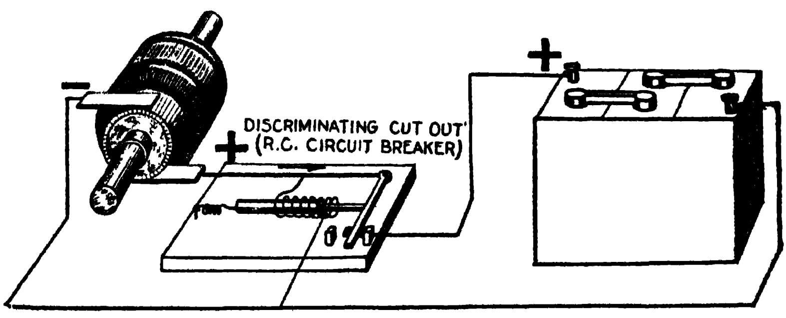
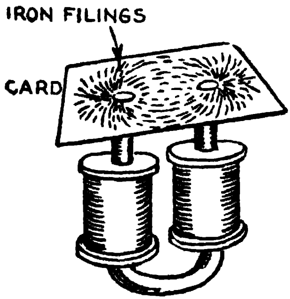


FIG. 6.—Dynamo charging battery illustrating current electricity. *A discriminating cut out* or *reverse current circuit breaker* is placed in the circuit to prevent battery discharging through dynamo if the voltage of the latter drop below that of the battery.

An electric current manifests itself by heating the wire or conductor; by causing a magnetic field around the conductor and by causing chemical changes in a liquid through which it may pass.

Dynamic Electricity.—This term is used to define current electricity to distinguish it from static electricity.

Magnetic Electricity.—The latest theory of magnetism, well supported by facts, assumes that *the molecules of a magnetic substance are minute magnets by nature, each having two poles.*



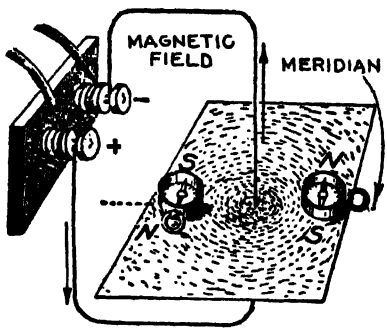


FIG. 7.—Ordinary horse shoe magnet with iron filings showing magnetic field.

FIG. 8.—Electromagnetic field surrounding a conductor with current flowing.

In a bar magnet, each molecule at the two ends may be supposed to have the attraction of its inward pointing pole neutralized more strongly than that of the outward pointing pole, which, therefore, is free to attract other bodies.

Radio Electricity.—In radio work *the electric waves representing the messages are transmitted, or propagated, from the sending station to the receiving station through the ether,* the latter performing the same functions as the wire does in ordinary telegraphy and telephony.

In radio communication it is first necessary to create waves in the ether or radio waves in varying groups and of varying strength, and second to intercept them with apparatus capable of changing them to sound waves.

The wave theory of radio is illustrated by the synchronous vibrations of a piano string and tuning fork as shown in fig. 9.

Atmospheric Electricity.—*The free electricity of the air which is almost always present in the atmosphere.* Its exact cause is unknown.

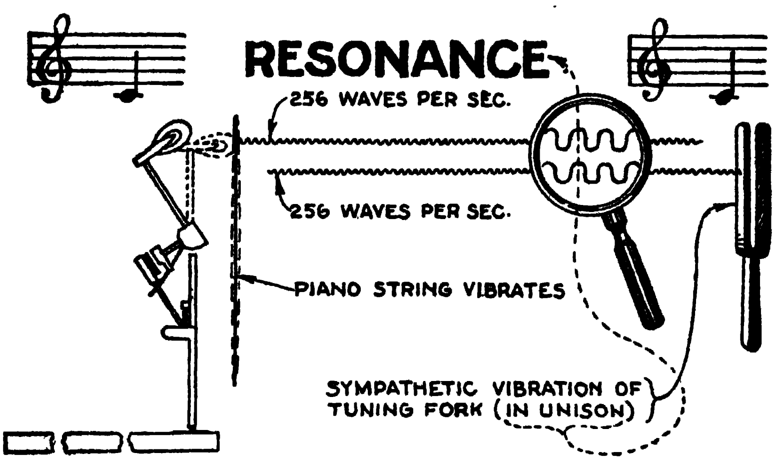


FIG. 9.—Sympathetic vibration of tuning fork with struck piano string when tuned to pitch, illustrating the wave theory of radio.

NOTE.—*In 1749, Benjamin Franklin,* observing lightning to possess almost all the properties observable in electric sparks, suggested that the electric action of points, which was discovered by him, might be tried on thunder clouds, and so draw from them a charge of electricity. He proposed, therefore, to fix a pointed iron rod to a high tower, but shortly after succeeded in another way. He sent up a kite during the passing of a storm, and found the wetted string to conduct the electricity to the earth, and to yield abundance of sparks. These he drew from a key tied to the string, a silk ribbon being interposed between his hand and the key for safety. Leyden jars could be charged, and all other electrical effects produced, by the sparks furnished from the clouds. The proof of the identity was complete. The kite experiment was repeated by Romas, who drew from a metallic string sparks 9 feet long. In 1753, Richmann, of St. Petersburg, who was experimenting with a similar apparatus, was struck by a sudden discharge and killed.

The phenomena of atmospheric electricity are of two kinds: there are the well known manifestations of thunder storms; and there are the phenomena of continual slight electrification in the air best observed when the weather is fine; the Aurora constitutes a third branch of the subject.

Positive Electricity.—This term expresses *the condition of the point of an electrified body having the higher energy from*

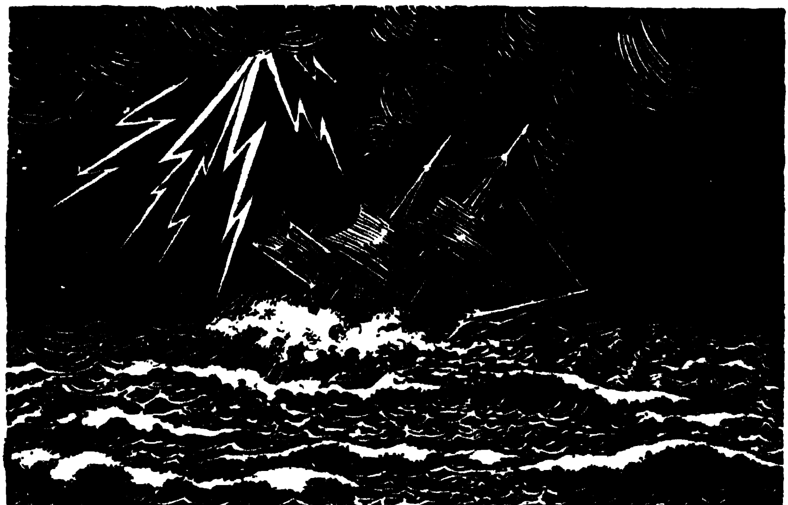
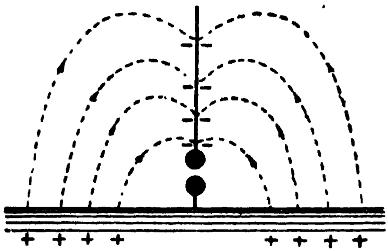


FIG. 10.—Thunder storm illustrating atmospheric electricity.

which it flows to a lower level. The sign which denotes this phase of electric excitement is +; all electricity is either positive or negative.

Negative Electricity.—This is *the reverse condition to the above* and is expressed by the sign or symbol −. These two terms are used in the same sense as *hot* and *cold*.



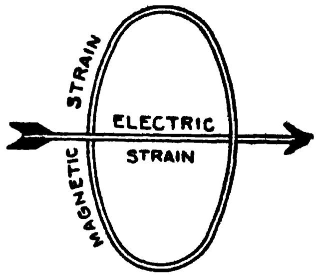


FIG. 11.—Electrostatic field about aerial.

FIG. 12.—Strains in the ether.

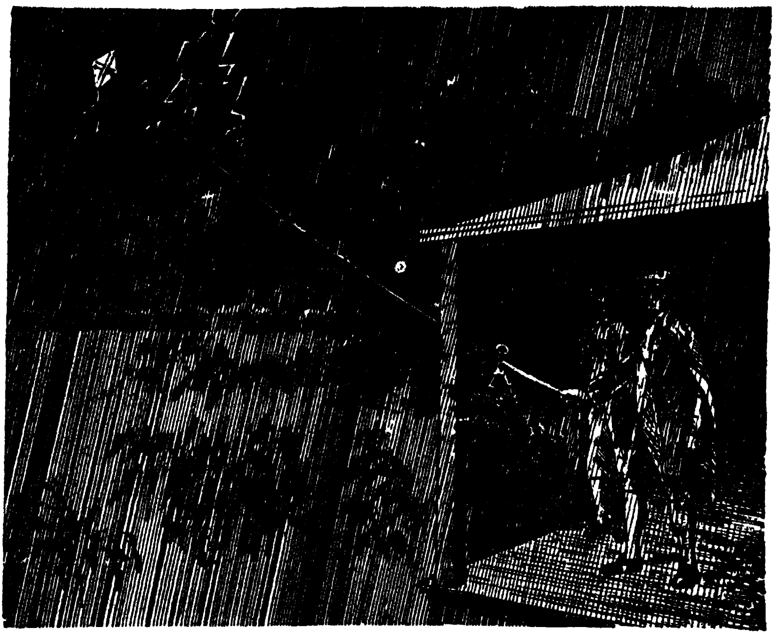
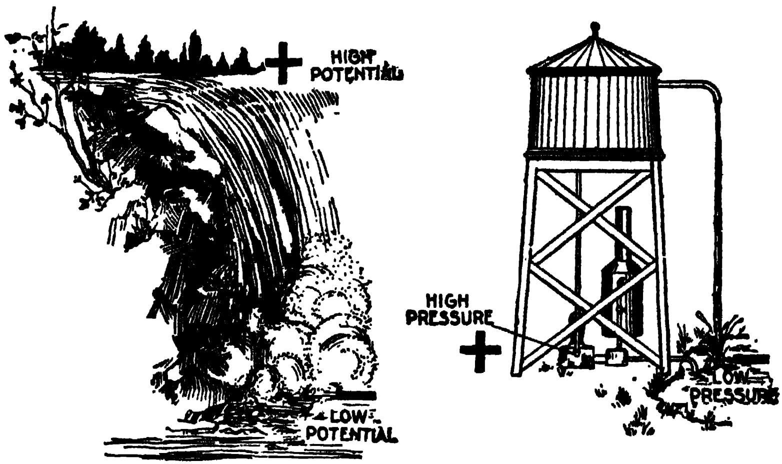


FIG. 13.—Franklin's kite experiment. He sent up a kite during a thunder storm and found the wetted string to conduct electricity to the earth and to yield an abundance of sparks.

Frictional Electricity.—*That kind of eleccricity produced by the friction of one substance against another.*

Resinous Electricity.—*The kind of electricity produced upon a resinous substance such as sealing wax, resin, shellac, rubber or amber when rubbed with wool or fur.* Resinous electricity is *negative electricity.*



FIGS 14 and 15.—Water fall and pumping station with tank overflowing illustrating + and - electricity.

Vitreous Electricity.—*A term applied to the positive electricity developed in a glass rod by rubbing it with silk.* This electric charge will attract to itself bits of pith or paper which have been repelled from a rod of sealing wax or other resinous substance which had been rubbed with wool or fur.

TEST QUESTIONS

1. *What is electricity?*
2. *What is Maxwell's idea of electricity?*
3. *How is electricity classified?*
4. *What is the difference between static and current electricity?*

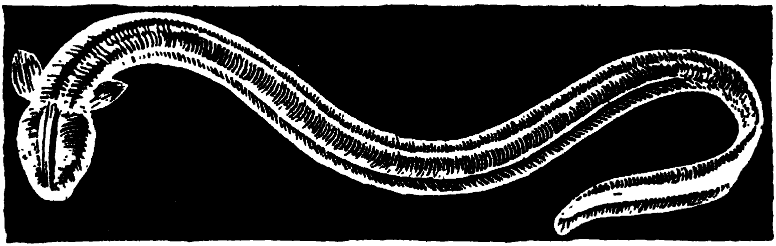


FIG. 16.—The electric eel. There are several species of so called electrical fishes. The Gymnotus or electric eel is common in all streams which flow into the Orinoco and is generally procured from Surinam. In the Surinam eel the electric apparatus extends the whole length of the body. It consists of four batteries, two on each side. These batteries consist of laminæ, composed of polygonal cells to the number of 800 or 1000, or more, supplied with four large bundles of nerve fibres; the under surface of the fish is —, the upper +. It is able to give a very severe shock, and is a formidable antagonist when it has attained its full length of 5 or 6 feet.

5. *How does an electric current manifest itself?*
6. *What is the latest theory of magnetism?*
7. *How are the molecules arranged in a bar magnet?*
8. *Explain radio communication.*
9. *What is the difference between positive and negative electricity?*
10. *Describe Benjamin Franklin's kite experiment.*

11. *Give some hydraulic analogies illustrating positive or negative electricity.*
12. *What length sparks were obtained by Romas in making Franklin's kite experiment?*
13. *How did Franklin protect himself in making the kite experiment?*
14. *What results were obtained by Richman of St. Petersburg?*

CHAPTER 2

Static Electricity

Static electricity may be defined simply as *electricity at rest;* the term properly applies to an isolated charge of electricity produced by friction. The presence of static electricity manifests itself by

1. Attraction, or
2. Repulsion.

Electrical Attraction and Repulsion.—When a glass rod, or a stick of sealing wax or shellac is held in the hand and rubbed with a piece of flannel or cat skin, the parts will be found to have the property of attracting bodies, such as pieces of silk, wool, feathers, gold leaf, etc.; they are then said to be *electrified*. In order to ascertain whether bodies are electrified or not, instruments called *electroscopes* are used.

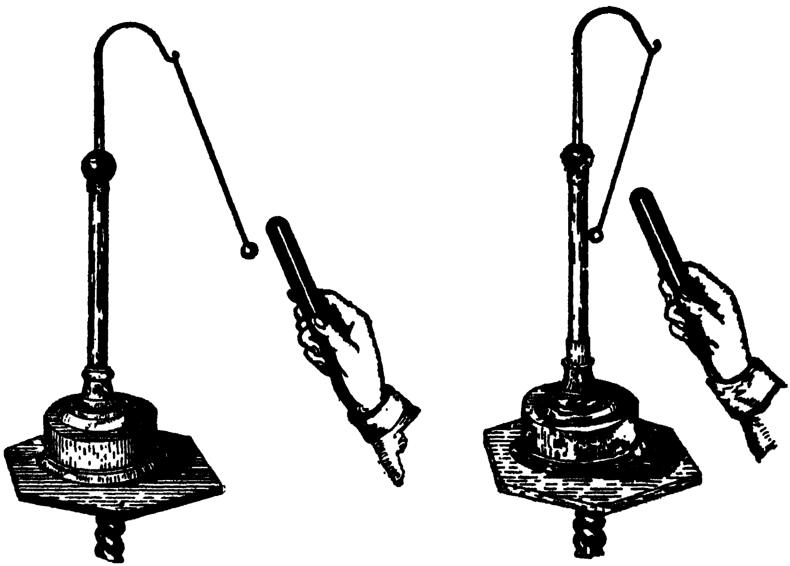
There are two opposite kinds of electrification:

1. Positive;
2. Negative.

Positive and Negative Electricity.—These terms signify that one body is charged to a higher pressure than the other, that is, by rubbing some of the charge is taken from one body and

transferred to the other as in figs. 19 to 22, the higher charge is arbitrarily called positive (+) and the lower negative (−) as in simile, *hot* and *cold*.

Franklin called the electricity excited upon the glass by rubbing it with silk ***positive*** electricity, and that



FIGS. 17 and 18.—Pith ball pendulum or electroscope; the figures illustrate also electrical attraction and repulsion.

produced on resinous bodies by friction with wool or fur, ***negative*** electricity.

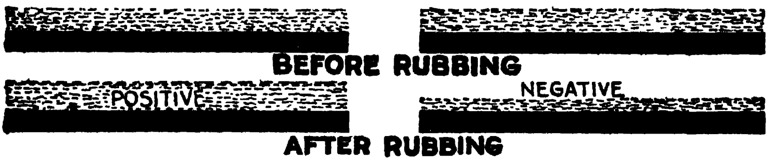
The electricity developed on a body by friction depends on the rubber as well as the body rubbed. Thus glass becomes negatively electrified when rubbed with catskin, but positively electrified when rubbed with silk.

The nature of the electricity set free by friction depends on the degree of polish, the direction of the friction, and the temperature. If two glass discs of different degrees of polish be rubbed against each other, that

which is most polished is positively electrified, and that which is least polished is negatively electrified.

If two silk ribbons of the same kind be rubbed across each other, that which is transversely rubbed is negatively and the other positively electrified. If two bodies of the same substance, of the same polish, but of different temperatures, be rubbed together, that which is most heated is negatively electrified. Generally speaking, the particles which are most readily displaced are negatively electrified.

In the following list, which is mainly due to Faraday, the substances are arranged in such order that each becomes posi-



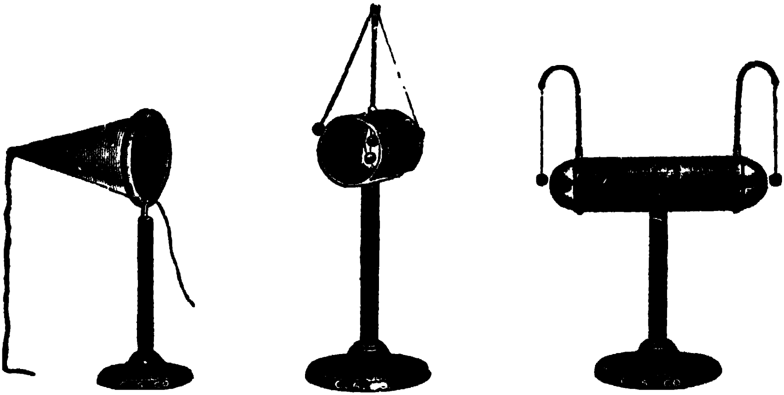
Figs 19 to 22.—Positive and negative electricity. The rubbing process removes electricity from one body transferring it to the other.

Figs. 23 to 25.—Equilization of oppositely changed bodies by contact.

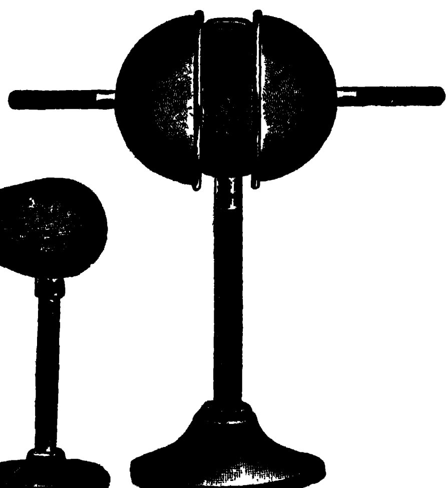
tively electrified when rubbed with any of the bodies following but negatively when rubbed with any of those which precede it:

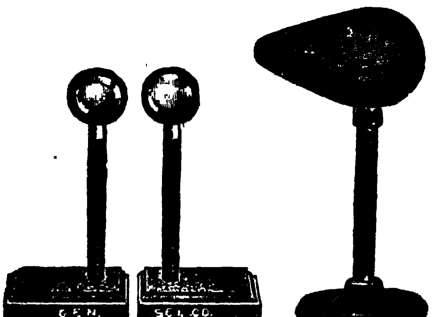
1. Catskin.	5. Glass.	9. Wood.	13. Resin.
2. Flannel.	6. Cotton.	10. Metals.	14. Sulphur.
3. Ivory.	7. Silk.	11. Caoutchouc.	15. Guttapercha
4. Rock crystal.	8. The hand.	12. Sealing wax.	16. Gun cotton.

Rule 1.—*If oppositely charged bodies be brought into contact with each other, the pressure will be equalized by the passing of the charge from the higher to the lower one.*



FIGS. 26 to 28.—Electrostatic apparatus. Fig. 26, Faraday's bag. When the bag is charged and pulled inside out, the static charge always remains on the outside Fig. 27, hollow cylinder with pith balls, showing that electricity resides only on the outer surfaces of bodies. Fig. 28, induction cylinder with removable pith ball



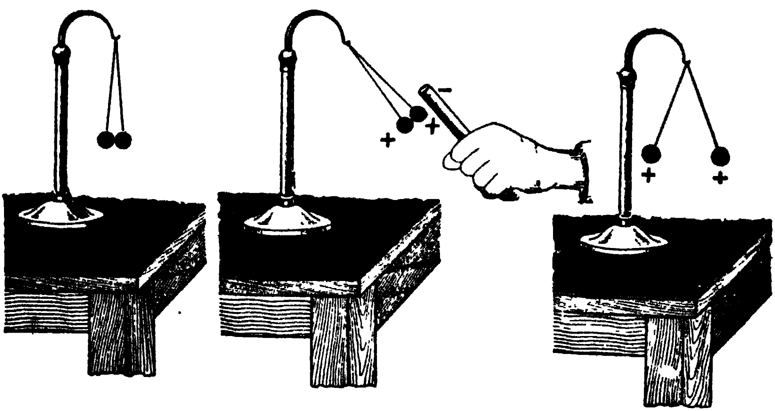


FIGS. 29 to 32.—Electrostatic apparatus. Fig. 29 and 30, induction spheres so mounted on insulating support that they can be brought into contact. Useful in connection with fig. 28 for showing the separation of positive and negative electricity by induction. Fig. 31, ellipsoidal conductor for showing unequal distribution. Fig. 32, Biot's hemispheres with pair of thin nickel plated brass hemispheres with rubber handles. Charge on outside of globe may be removed by placing hemispheres in position shown.

When the pressures are thus equalized the bodies are said to be discharged. Where the pressure difference is small, contact is necessary (figs. 23 to 25), but where it is great, it is only necessary to bring the bodies close together as in figs. 21 and 22.

Rule 2.—*A body charged with one kind of electricity repels one charged with the same kind, and attracts one charged with the opposite kind.*

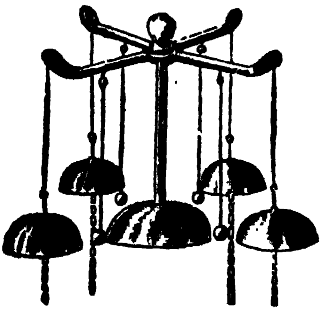
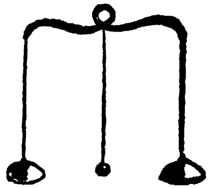
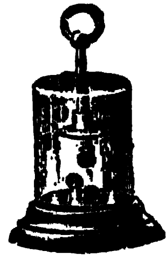
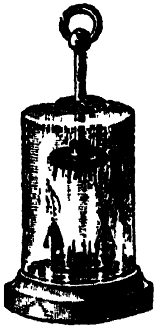
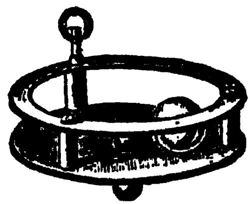
Whenever two bodies are rubbed together the body rubbed receives a charge unlike that of the rubbing body, as stated.



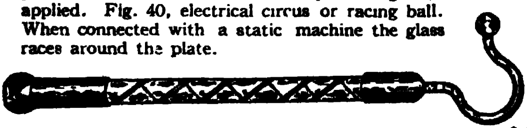
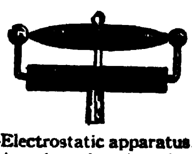
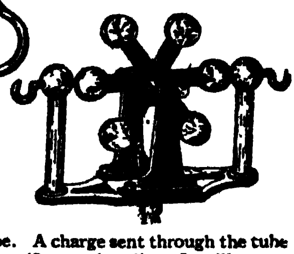
FIGS. 33 to 35.—Electrical attraction and repulsion.

Rule 3.—*Whenever a positive charge is developed an equal negative charge is developed, and vice-versa.*

The Charge.—*The quantity of electrification of either kind produced by friction or other means upon the surface of a body* is called a charge, and a body when electrified is said to be *charged.*

Figs. 36 to 40.—Electrostatic apparatus. Fig. 36, electrical chimes to illustrate attraction and repulsion of charge. Fig. 37, electrical chime arranged to be suspended from static machine. Fig. 38, Volta's hail storm or dancing balls. The charge from static machine causes balls to dance rapidly. Fig. 39, smoke condenser. The glass shade is filled with smoke from a punk candle, which is condensed upon the glass, when a charge from a static machine is applied. Fig. 40, electrical circus or racing ball. When connected with a static machine the glass races around the plate.

Figs. 41 to 43.—Electrostatic apparatus. Fig. 41, spiral tube. A charge sent through the tube will show a series of sparks where it crosses the gaps. Fig. 42, rotating disc. It will rotate rapidly when connected to a static machine. Fig. 43, electrostatic motor. It will rotate at high speed when connected to static machine.

It is clear that there may be charges of different values as well as of either kind. When the charge of electricity is removed from a charged body it is said to be *discharged*.

Good conductors of electricity are quickly discharged if touched by the hand or by any conductor in contact with the ground, the charge thus finding a means of escaping to earth.

A body that is not a good conductor may be readily discharged by passing it rapidly through the flame of a lamp or candle; for the flame carries off the electricity and dissipates it in the air.

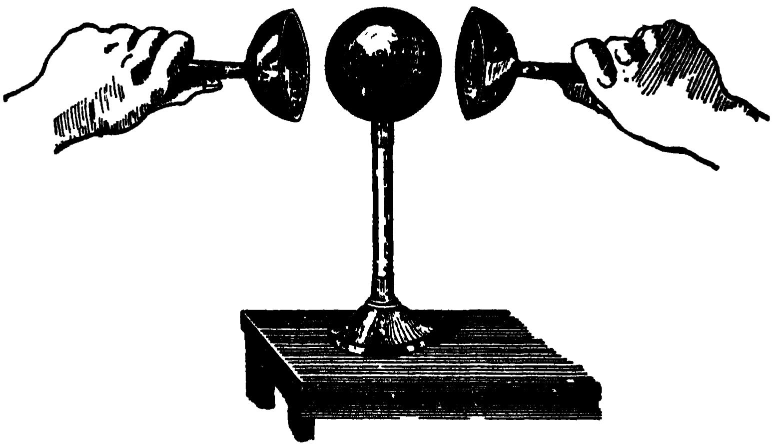


FIG. 44.—Boits experiment which proved that the *charge resides on the surface*.

Distribution of the Charge.—When an insulated sphere of conducting material is charged with electricity, the latter passes to the surface of the sphere, and forms there an extremely thin layer. The distribution of the charge then, depends on the *extent* of the surface and not on the mass.

Boit proved that the charge resides on the surface by the following experiment:

A copper ball was electrified and insulated. Two hollow hemispheres

of copper of a larger size, provided with glass handles, were then placed near the sphere, as in fig. 44. So long as they did not touch the sphere, the charge remained on the latter, but if the hemipsheres touched the inner sphere, the whole of the electricity passed to the exterior, and when the hemispheres were separated and removed the inner globe was found to be completely discharged.

The distribution of a charge over an insulated sphere of conducting material is uniform, provided the sphere is remote from all other conductors and electrified bodies.

FIGS. 45 to 48.—Illustrating the distribution of the charge on conductors of various shapes.

Figs. 45 to 48 show, by the dotted lines, the distribution of a charge for bodies of various shapes. Fig. 46 shows that for elongated bodies, the charge collects at the ends.

The effects of points is illustrated in fig. 50; when a charged body is provided with a point as here shown, the current accumulates at the point to such a high degree of density that it passes off into the air, and if a lighted candle be held in front of the point, the flame will be visibly blown aside.

Fig. 51 shows an *electric wind mill* or experimental device for illustrating the escape of electricity from points. It consists of a vane of several pointed wires bent at the tips in the same direction, radiating from a center which rests upon a pivot. When mounted upon the conductor of an electrostatic machine, the vane rotates in a direction opposite that of the points. The movement of the vane is due to the repulsion of the electrified air particles near the points and the electricity on the points themselves. The motion of the air is called *electric wind*. This device is also called *electric flyer*, and *electric whirl*.

"Free" and "Bound" Electricity.—These terms may be defined as follows:

The expression *free electricity* relates to the ordinary state of electricity upon a charged conductor, not in the presence of a

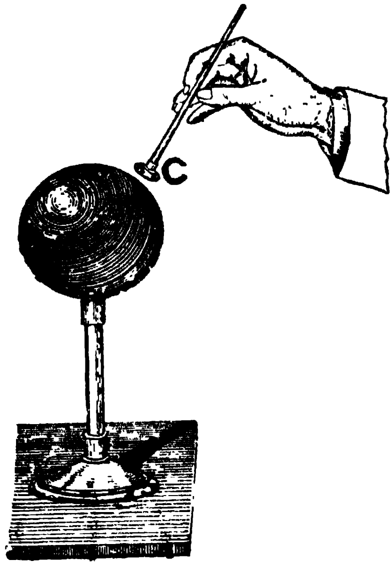


FIG. 49.—Distribution of electrification on a charged hollow sphere. If an insulated conductor C, be inserted through the opening in the sphere and brought into contact with the interior surface and afterwards carefully removed, it will be found, by testing with the gold leaf electroscope, that it has received no charge. If touched to the outside, however, the conductor will receive part of the charge.

charge of the opposite kind. A free charge will flow away to the earth if a conducting path be provided.

A charge of electricity upon a conductor is said to be *bound*, when it is attracted by the presence of a neighboring charge of the opposite kind.

149 40

Conductors and Insulators.—The term *conductors* is applied to those bodies *which readily allow electricity to flow through them, in distinction from* **insulators** *or so called* **non-conductors**, *which practically allow no flow of electricity.*

Strictly speaking, there is no substance which will prevent the passage of electricity, hence, the term non-conductors, though extensively used, is not correct.

Electroscopes.—These are instruments *for detecting whether a body be electrified or not, and indicating also whether the elec-*

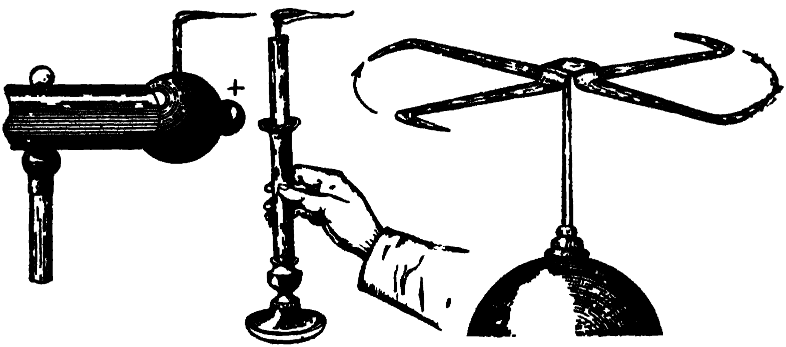


FIG. 50.—Experiment to illustrate the effect of pointed conductors.
FIG. 51.—Electric wind mill which operates by the reaction due to the escape of the electric charge from the points.

trification be ***positive*** *or* ***negative***. The earliest electroscope devised consisted of a stiff straw balanced lightly upon a sharp point; a thin strip of brass or wood, or even a goose quill, balanced upon a sewing needle will serve equally well. Another form of electroscope is the pith ball pendulum, shown in figs. 17 and 18.

When an electrified body is held near the electroscope *it is attracted or repelled thus indicating the presence and nature of the charge.*

Gold Leaf Electroscope.—This form of electroscope, which is very sensitive, was invented by Bennet. Its operation depends on the fact that *like charges repel each other.*

The gold leaf electroscope as shown in fig. 52, is conveniently made by suspending the two narrow strips of gold leaf within a wide mouthed glass jar, which both serves to protect them from draughts of air and to support them from contact with the ground. A piece of varnished glass tube is pushed through the

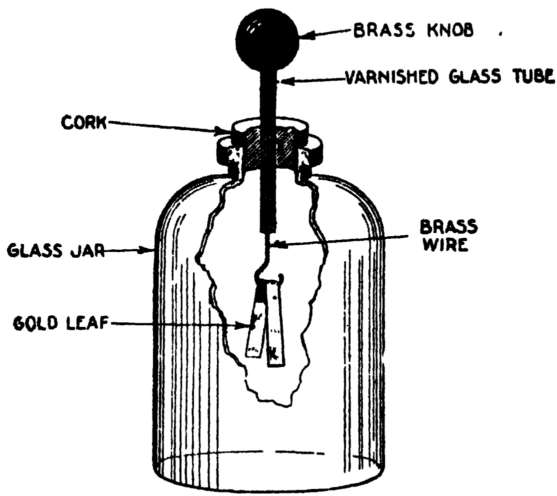


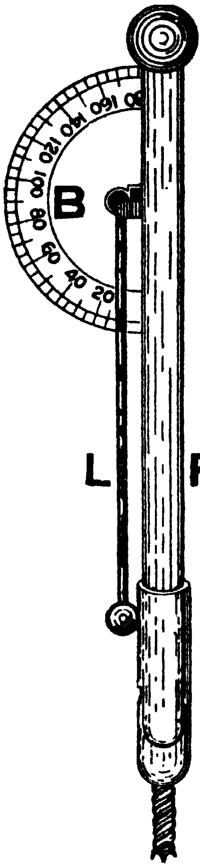
FIG. 52.—Gold leaf electroscope. *It consists of* two strips ot gold foil suspended from a brass rod within a glass jar. Used to detect the presence and sign of an electric charge.

cork, which should be varnished with shellac or with paraffin wax. Through this passes a stiff brass wire, the lower end of which is bent at a right angle to receive the two strips of gold leaf, while the upper end is attached to a flat plate of metal, or may be furnished with a brass knob.

When kept dry and free from dust it will indicate excess of

small quantities of electricity. A rubbed glass rod, even while two or three feet from the instrument, will cause the leaves to repel one another.

If the knob be brushed with only a small camel's hair brush, the slight friction produces a perceptible effect.



With this instrument all kinds of friction can be shown to produce electrification.

The gold leaf electroscope can be further used to indicate the *kind* of electricity on an excited body. Thus, if a piece of brown paper be rubbed with a piece of india rubber, the nature of the charge is determined as follows:

First charge the gold leaves of the electroscope by touching the knob with a glass rod rubbed on silk. The leaves diverge, being electrified with positive electrification. When they are thus charged the approach of a body which is positively electrified will cause them to diverge still

FIG. 53.—Henley's quadrant electroscope used to indicate large charges of electricity. *In construction,* pith ball placed on a light arm L, of straw or other similar material is pivoted at the center of a graduated circle B. The arm F, is attached by means of the screw to the prime conductor of an electric machine. The similar charge imparted to L, by contact with F causes a repulsion which may be measured on the graduated arc. This instrument approaches the electrometer in the character of its operation, since by its means, approximately correct measurements may be made of the value of the repulsion. It should not, however, be confounded with the *quadrant electrometer*.

more widely; while, on the approach of one negatively electrified, they will tend to close together. If now the brown paper be brought near the electroscope, the leaves will be seen to diverge more, proving the electrification of the paper to be of the same kind as that with which the electroscope is charged.

The gold leaf electroscope will also indicate roughly the amount of electricity on a body placed in contact with it, for the gold leaves open out more widely when the quantity of electricity thus imparted to them is greater.

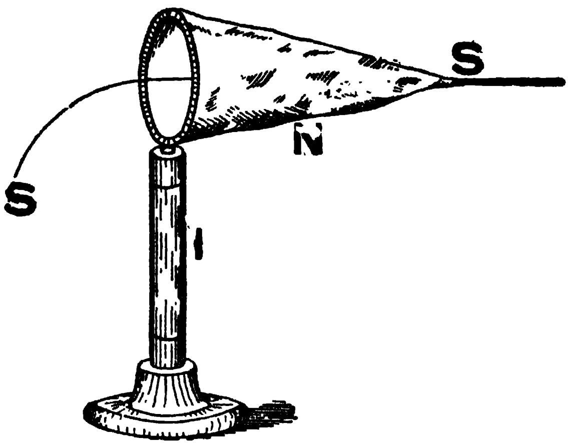


FIG. 54.—Faraday's net. *It consists of,* a bag N, of cotton gauze, or mosquito netting supported on an insulating stand I. When tested by a proof plane, no free electric charge is found on the inside, though such a charge is readily detected by the same means on the outside. By the aid of the silk strings S,S, the bag can be turned inside out, when the charge will then all be found on the then inside, or the now outside.

Ques. Why are gold leaves used rather than thinnest tissue paper?

Ans.—The gold leaves, being excessively thin, are much lighter than the thinnest paper and therefore more sensitive.

Electric Screens.—That the charge on the outside of a

conductor always distributes itself in such a way that there is no electric force within the conductor was first proved experimentally by Faraday. He covered a large box with tin foil and went inside with the most delicate electroscope obtainable. Faraday found that *the outside of the box could be charged so strongly that long sparks would fly from it without any electrical effects being observable anywhere inside the box.*

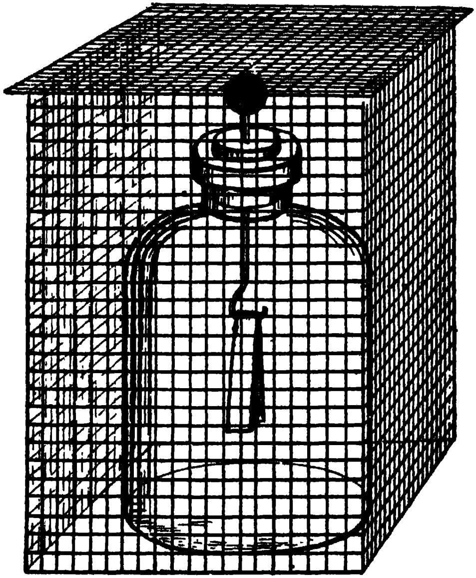


FIG. 55.—The electric screen. A screen of wire gauze surrounding a delicate electrical instrument will protect it from external electrostatic induction.

To repeat the experiment in modified form, let an electroscope be placed beneath a bird cage or wire netting, as in fig. 55. Let charged rods or other powerfully charged bodies be brought near the electroscope outside the cage. The leaves will be found to remain undisturbed.

Electrification by Induction.—An insulated conductor,

charged with either kind of electricity, acts on bodies in a neutral state placed near it in a manner *analogous to that of the action of a magnet on soft iron;* that is, it decomposes the neutral electricity, attracting the opposite and repelling the like kind of electricity. The action thus exerted is said to take place by *influence* or *induction.*

The phenomenon of electrification by induction may be demonstrated by the following experiment:

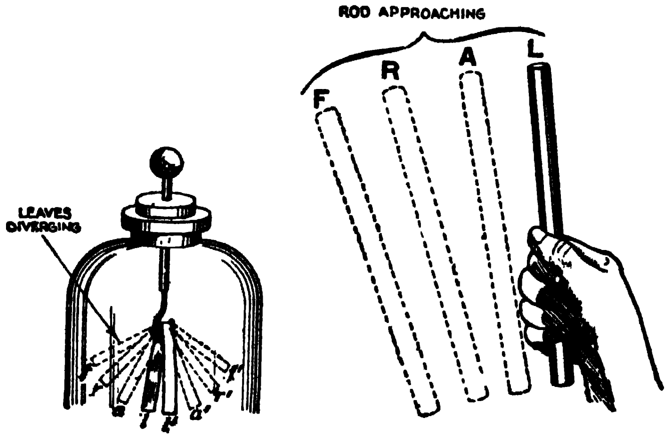


FIG. 56.—Experiment to illustrate electrostatic induction. *The leaves will diverge, even* though the charged ebonite rod does not approach to within a foot of the electroscope. Thus as the rod approaches the electroscope, positions L,A,R,F, the leaves will diverge as indicated by positions *ll′*, *aa′*, *rr′*, *ff′*.

In fig. 56, let the ebonite rod be electrified by friction and slowly brought toward the knob of the gold leaf electroscope. The leaves will be seen to diverge, even though the rod does not approach to within a foot of the electroscope.

This experiment shows that the mere *influence* which an electric charge exerts upon a conductor placed in its vicinity

is able to produce electrification in that conductor. This method of producing electrification is called ***electrostatic induction***.

As soon as the charged rod is removed the leaves will collapse, indicating that this form of electrification is only a temporary phenomenon which is due simply to the presence of the charged body in the neighborhood.

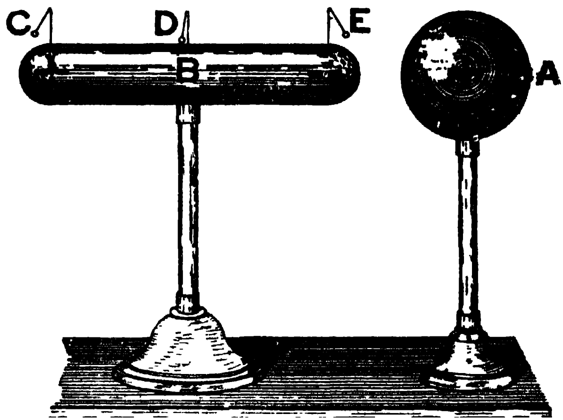


FIG. 57.—Experiment illustrating the nature of an induced charge. The apparatus consists of a metal ball and cylinder, both mounted on insulated stands, pith balls being placed on the cylinder at points C, D, and E.

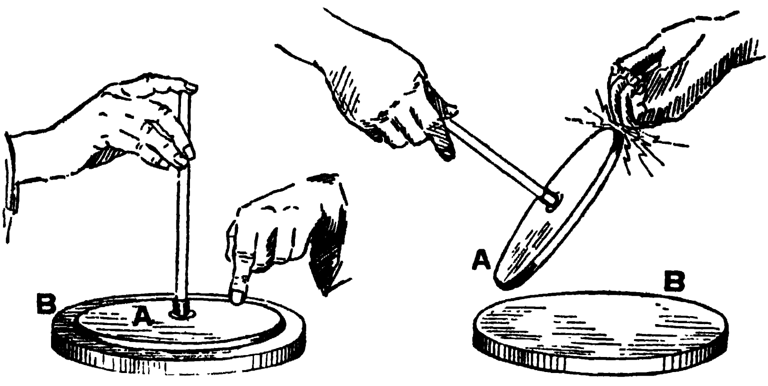
Nature of the Induced Charge.—This is shown by the experiment illustrated in fig. 57.

Let a metal ball A, be charged by rubbing it with a charged rod, and let it then be brought near an insulated metal cylinder B, which is provided with pith balls or strips of paper C,D,E, as shown.

The divergence of C and E, will show that the ends of B, have received electrical charges because of the presence of A, while the failure of D, to diverge will show that the middle of B, is uncharged. Further, the rod which charged A, will be found to repel C, but to attract E.

From these experiments, the conclusion is that when a conductor is brought near a charged body, the end away from the inducing charge is electrified with the same kind of electricity as that on the inducing body, while the end toward the inducing body receives electricity of opposite sign.

The Electrophorus.—This is a simple and ingenious instrument, invented by Volta in 1775 for the purpose of procuring, by the principle of induction, ***an unlimited number of charges of electricity from one single charge.***



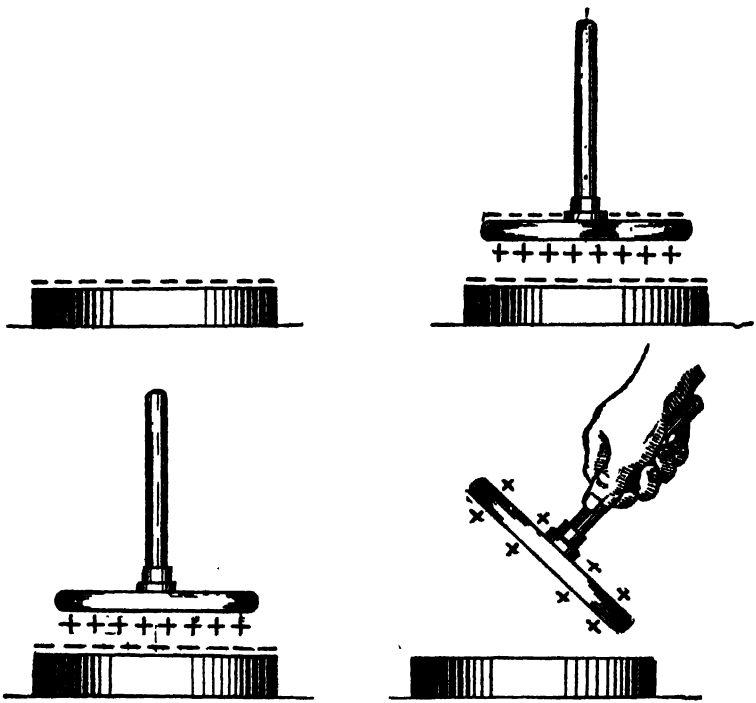
FIGS. 58 and 59.—The electrophorus and method of using. Charge B; place A, in contact with B, and touch A, (fig. 58). The disc is now charged by *induction* and will yield a spark when touched by the hand, as in fig. 59.

It consists of two parts, as shown in fig. 59, a round cake of resinous material B, cast in a metal dish or "sole" about one foot in diameter, and a round disc A, of slightly smaller diameter made of metal or of wood covered with tinfoil, and provided with a glass handle. Shellac, or sealing wax, or a mixture of resin shellac and Venice turpentine, may be used to make the cake.

To use the electrophorus, ***the resinous cake B, must be first***

beaten or rubbed with fur or a woolen cloth, the disc A, is then placed on the cake, touched with the finger and then lifted by the handle. The disc will now be found to be charged and will yield a spark when touched with the hand, as in fig. 59.

The "cover" may be replaced, touched, and once more removed, and

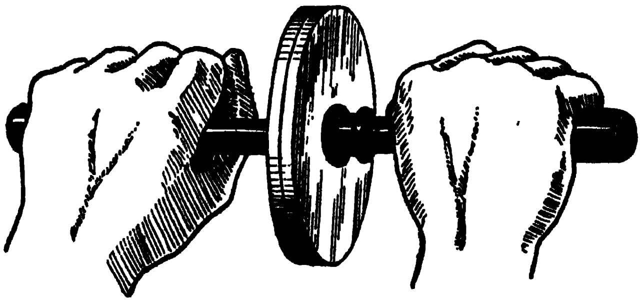


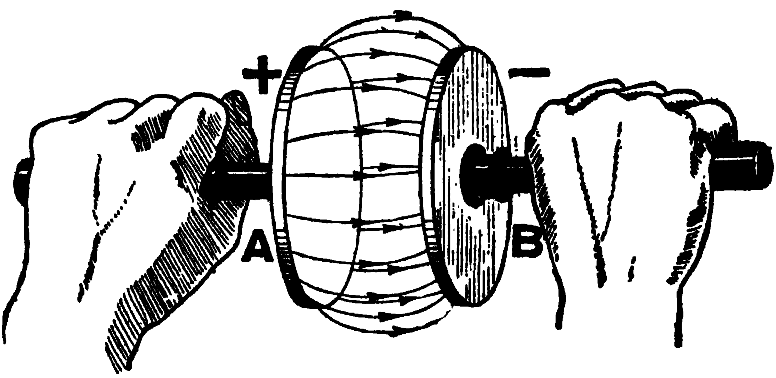
FIGS. 60 to 63.—Illustrating "how the electrophorus works."

will thus yield any number of sparks, the original charge on the resinous plate meanwhile remaining practically as strong as before.

The theory of the electrophorus is very simple, provided the student has clearly grasped the principle of induction.

When the resinous cake is first beaten with the cat's skin its surface is negatively electrified, as indicated in fig. 60. Again, when the metal disc is placed down upon it, it rests really only on three or four points of the surface, and may be regarded as an insulated conductor in the presence of an electrified body. The negative electrification of the cake therefore acts inductively on the metallic disc or "cover," attracting a positive





FIGS. 64 and 65.—Electrification produced by rubbing dissimilar bodies together and then separating them. If the insulated glass and leather discs A and B, be rubbed together, *but not separated*, no signs of electrification can be detected; but if the discs be drawn apart a little distance the space between them is found to be an electric field, and as they separate farther and farther, electric forces will be found to exist in more and more of the surrounding space, the electrification being indicated by "lines of force." It should be noted that *work has to be done* in separating the charged discs to overcome the attraction which tends to hold them together. The stress indicated by the lines of force consists of a tension or pull in the direction of their length and a pressure or thrust at right angles to that direction.

charge to its under side, and repelling a negative charge to its upper surface, as shown in fig. 61.

If, now, the cover be touched for an instant with the finger, the negative charge of the upper surface (which is upon the upper surface being repelled by the negative charge on the cake) will be neutralized by electricity flowing in from the earth through the hand and body of the experimenter. The attracted positive charge will, however remain, being bound as it were by its attraction toward the negative charge on the cake.

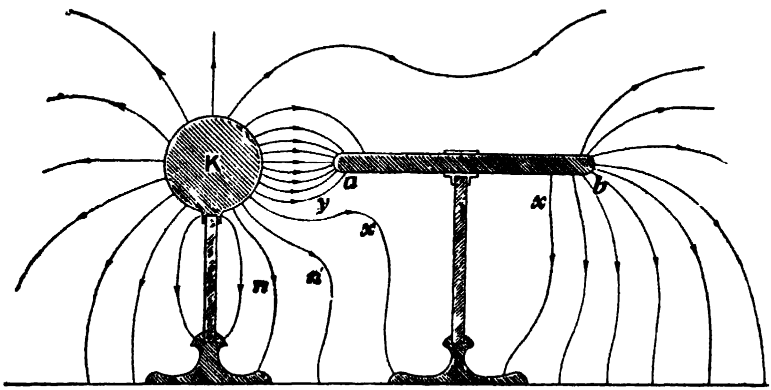


FIG. 66.—Lines of force of a charged sphere and a conductor under induction. The negative electrification on the end *a*, of the cylinder indicates that a certain number of lines end there, while the positive electrification on the end *b*, similarly indicates that an *equal* number of lines set out from that end. It is one of the fundamental properties of a conductor that it yields instantly to the smallest electric force, and that no electric force can be permanently maintained within the substance of a conductor in which no current is passing. There can, therefore, be no electrostatic strain and no lines of force within the material of a conductor where the electric field has become steady. Hence the lines starting from *b*, are entirely distinct from those ending at *a*. The two sets are equal in number because no charge has been given to the cylinder, either positive or negative, and therefore the sum of all the positive electrifications (or lines starting from *b*) must be equal to the sum of all the negative electrifications (or the lines ending at *a*). In all nine lines have been drawn at each end of the cylinder, leaving the thirteen lines emanating from the sphere which do not run on to the cylinder. If the cylinder be withdrawn to a distance from K, it (the cylinder) will be found to show no signs of electrification.

Fig. 62 shows the result after the cover has been touched. If, finally, the cover be lifted by its handle, the remaining positive charge will no longer be "*bound*" on the lower surface by attraction, but will distribute itself on both sides of the cover, and may be used to give a spark. It is clear that no part of the original charge has been consumed in the process,

which may be repeated as often as desired. As a matter of fact, the charge on the cake slowly dissipates, especially if the air be damp. Hence it is needful sometimes to renew the original charge by again beating the cake with the cat's skin.

The labor of touching the cover with the finger at each operation may be saved by having a pin of brass or a strip of tinfoil projecting from the

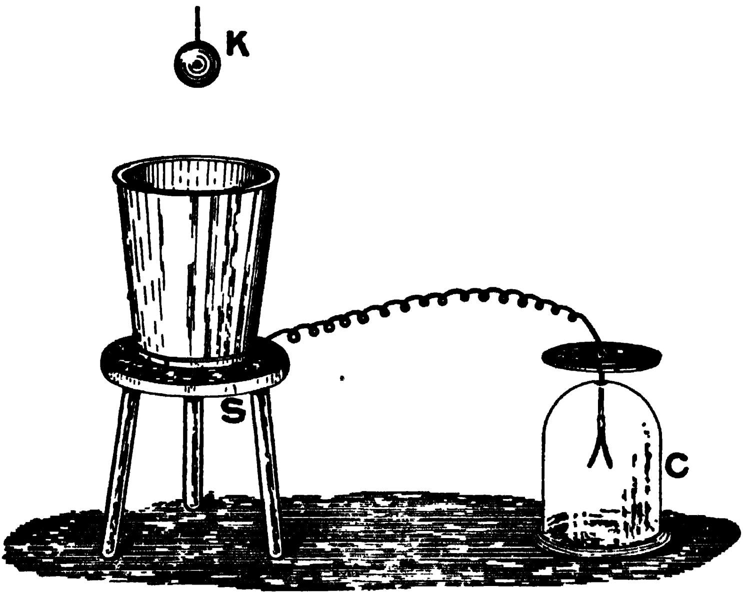
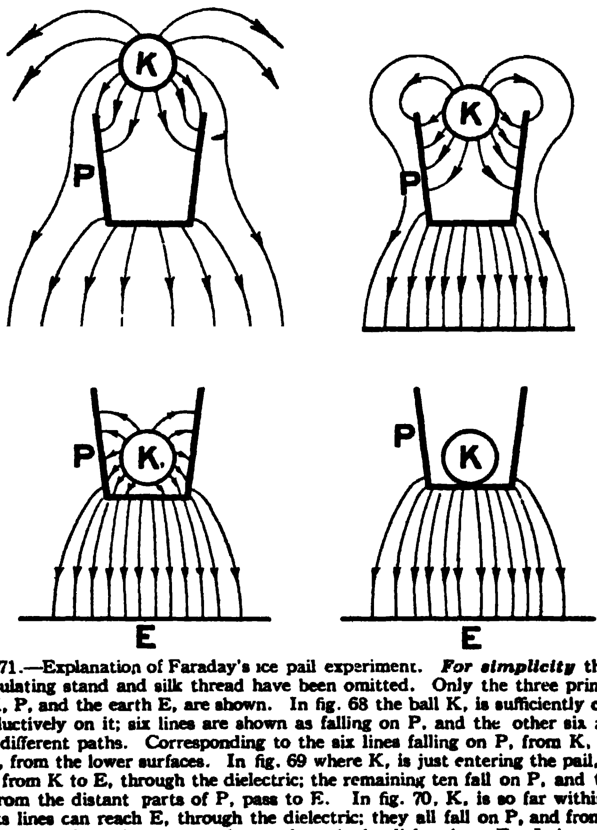


FIG. 67.—Faraday's ice pail experiment An ice pail P, connected with the gold leaves of an electroscope C, is placed on an insulating stand S. A. charged conductor K, carried by a silk thread, is lowered into the pail, and finally touches it at the bottom. While it is being lowered the leaves of the electroscope diverge farther and farther, until K, is well within the pail, after which they diverge no more, even when K, touches the pail or is afterwards withdrawn by the insulating thread. After withdrawal, K, is found to be completely discharged.

metallic "sole" on to the top of the cake, so that it touches the plate each time, and thus neutralizes the negative charge by allowing electricity to flow in from the earth.

Since the electricity thus yielded by the electrophorus is not

obtained at the expense of any part of the original charge, it is a matter of some interest to inquire whence is the source from



FIGS. 68 to 71.—Explanation of Faraday's ice pail experiment. *For simplicity* the electroscope, insulating stand and silk thread have been omitted. Only the three principal conductors K, P, and the earth E, are shown. In fig. 68 the ball K, is sufficiently close to P, to act inductively on it; six lines are shown as falling on P, and the other six as passing to E, by different paths. Corresponding to the six lines falling on P, from K, six others pass to E, from the lower surfaces. In fig. 69 where K, is just entering the pail, two lines only pass from K to E, through the dielectric; the remaining ten fall on P, and ten others starting from the distant parts of P, pass to E. In fig. 70, K, is so far within P, that none of its lines can reach E, through the dielectric; they all fall on P, and from the outside of P, an equal number start and pass through the dielectric to E. It is evident that in this position K, can be moved about within P, without affecting the outside distribution in the slightest, and that even when K, touches P, as shown in fig. 71, and when, therefore, all lines between them disappear, the lines in the dielectric outside remain just as they are in fig. 70. K, is now completely discharged, since lines no longer emanate from it, hence it can be removed by the silk cord without disturbing the electrification of P. If K, be again charged and introduced into P, it will be again discharged, for the fact that P, is already charged will have no effect on the final result, provided when K, touches P it is well *under cover.*

which the energy of this apparently unlimited supply is drawn; for it cannot be called into existence without the expenditure of some other form of energy. The fact is, *more work is done in lifting the cover when it is charged with the positive electricity*

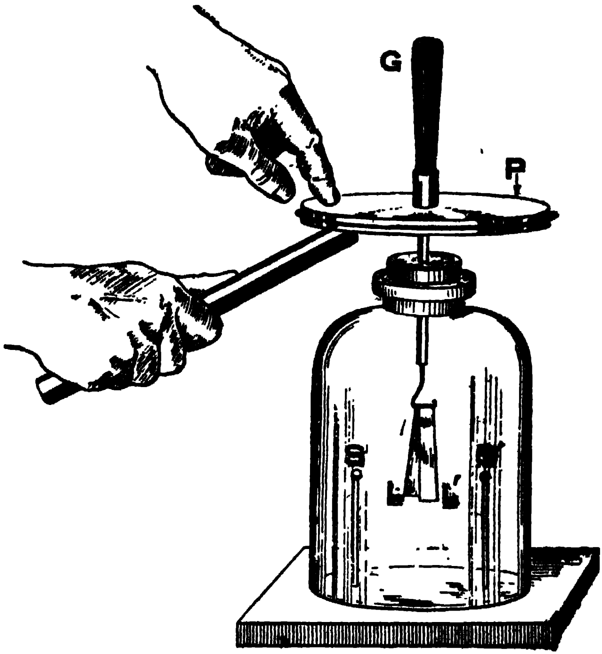
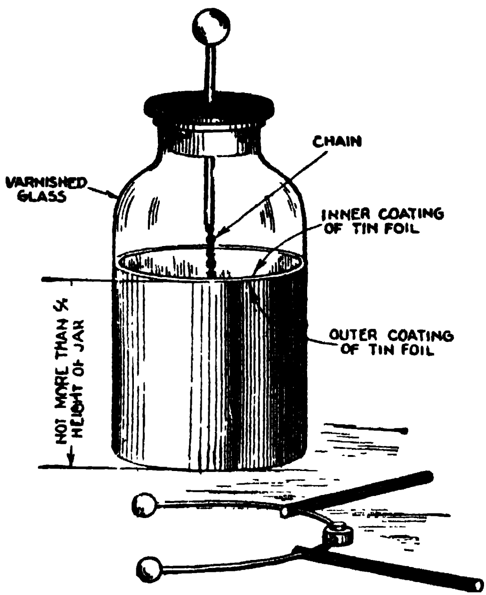


FIG. 72.—Volta's condensing electroscope. *It consists of* two metallic plates placed at the top of the instrument, and separated by a suitable dielectric. The upper plate P, is removable by means of the insulated handle G. To employ the electroscope, as for example, to detect the free charge in an unequally heated crystal of tourmaline, the crystal is touched to the lower plate, while the upper plate is connected to the ground by the finger. On the subsequent removal of the upper plate an enormous decrease ensues in the capacity of the condenser, and the charge now raises the pressure of the lower plate, and causes a marked divergence of the leaves L,L'. Two parts S,S' connected with the earth increases the amount of divergence by induction.

than when it is not charged; for when charged, there is the force of the electric attraction to be overcome as well as the

force of gravity; this excess force is the real origin of the energy stored up in the separate charges.

Condensers; Leyden Jar.—A *condenser* is an apparatus for condensing a large quantity of electricity on a comparatively small surface. The form may vary considerably, but in all



FIGS. 73 and 74.—The Leyden jar and discharger. Its discovery is attributed to the attempt of Musschenbrock and his pupil Cuneus t· collect the supposed electric "fluid" in a bottle half filled with water. The bottle was held in the hand and was provided with a nail to lead the "fluid" down through the cork to the water from the electric machine. The invention of the Leyden jar is also claimed by Kleist, Bishop of Pomerania.

cases it *consists essentially of two insulated conductors, separated by an insulator and the working depends on the action of induction.*

A form of condenser generally used in making experiments on static electricity is the Leyden jar, so named from the town of Leyden where it was invented.

It consists of a glass jar coated inside and out to a certain height with tinfoil, having a brass rod terminating in a knob passed through a wooden stopper, and connected to the inner coat by a loose chain, as shown in fig. 73.

FIGS. 75 to 77.—Knott demonstration Leyden jars for demonstrating that an electric charge resides as potential energy in the glass of a Leyden jar and not in the metallic coatings. This is a dissectible Leyden Jar, the outer metallic covering being removable as well as the inner. The inner is provided with a rod with ball terminal for charging.

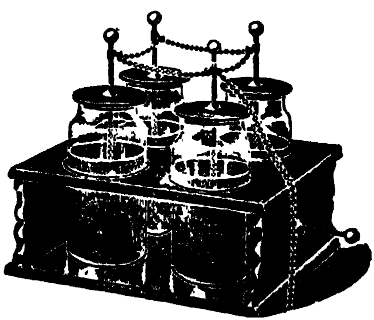


FIG. 78.—Knott four jar Leyden battery for demonstrating optically the distribution of static electricity over the surface of a condenser being charged and discharged.

The jar may be charged *by repeatedly touching the knob with the charged plate of the electrophorus or by connecting the inner coating to one knob of an electrical machine and the outer coatıng to the other knob.*

The discharge of a condenser is effected *by connecting the plates having an opposite charge.*

This may be done by use of a wire or a discharger, as shown in figs. 73 and 74; the connection is made between the outer coat and the knob.

When the knob of the discharger is sufficiently close to the knob of the jar, a bright spark will be observed between the knobs. Tnis discharge

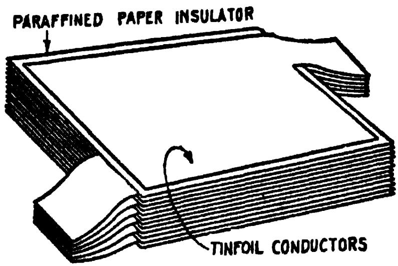


FIG. 79.—Condenser for induction coil. *In construction*, numerous sheets of tin foil are prepared and placed on top of each other with a thin layer of insulating material betweer as shown.

occurs whenever the difference of pressure between the coats is great enough to overcome the resistance of the air between the knobs.

Let a charged jar be placed on a glass plate so as to insulate the outer coat. Let the knob be touched with the finger. No appreciable discharge will be noticed. Let the outer coat be in turn touched with the finger. Again no appreciable discharge will appear. However if the inner and outer coatings be connected with the discharger, a powerful spark will pass.

Electric Machines.—Various machines have been devised for producing electric charges such as have been described. The ordinary "static" or electric machine, is nothing but *a continuously acting electrophorus.*

Fig. 80 represents the so called Toepler-Holtz machine. Upon the back of the stationary plate E, are pasted paper sectors, beneath which are strips of tinfoil AB and CD, called *inductors*.

In front of E, is a revolving glass plate carrying discs *l,m,n,o,p*, and *q*, called *carriers*.

To the inductors *AB* and *CD*, are fastened metal arms *t* and *u*, which bring *B* and *C*, into electrical contact with the discs *l,m, n,o,p*, and *q*, when these discs pass beneath the tinsel brushes carried by *t* and *u*.

A stationary metallic rod *rs*, carries at its ends stationary brushes as well as sharp pointed metallic combs.

The two knobs *R* and *S*, have their capacity increased by the Leyden jars *L* and *L'*.

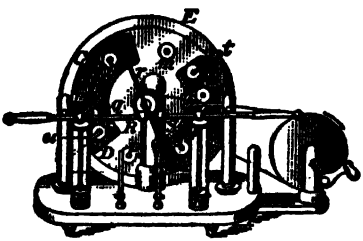


FIG. 80.—The Toepler-Holtz electric machine.

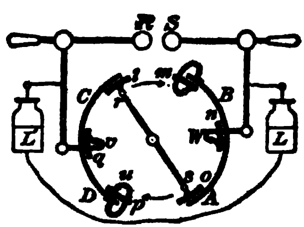


FIG. 81.—Principle of Toepler-Holtz electric machine.

Action of the Toepler-Holtz Machine.—The action of the machine described above is best understood from the diagram of fig. 81.

Suppose that a small + charge is originally placed on the inductor *CD*. Induction takes place in the metallic system consisting of the discs *l* and *o*, and the rod *rs*, *l* becoming negatively charged and *o*, positively charged.

As the plate carrying *l,m,n,o,p,q*, rotates in the direction of the arrow the negative charge on *l*, is carried over to the position *m*, where a part of it passes over to the inductor *AB*, thus charging it negatively.

When l, reaches the position n, the remainder of its charge, being repelled by the negative electricity which is now on AB, passes over into the Leyden jar L.

When l, reaches the position o, it again becomes charged by induction, this time positively, and more strongly than at first, since now the negative charge on AB, as well as the positive charge on CD, is acting inductively upon the rod rs.

When l, reaches the position u, a part of its now strong positive charge passes to CD, thus increasing the positive charge upon this inductor.

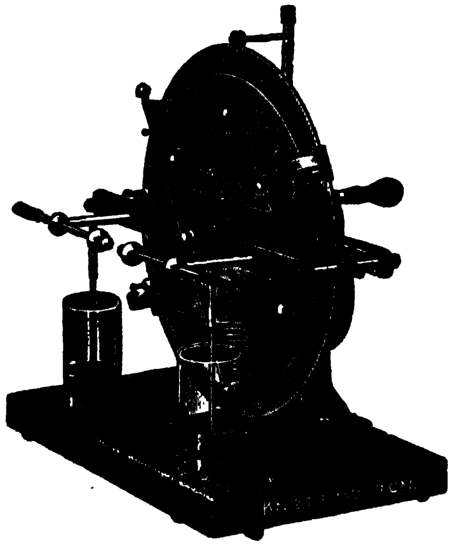


FIG. 82.—The Toepler-Holtz Electric Machine.

In the position v, the remainder of the positive charge on l, passes over to L'. This completes the cycle for l. Thus as the rotation continues AB and CD, acquire stronger and stronger charges, the inductive action upon rs, becomes more and more intense, and positive and negative charges are continuously imparted to L' and L, until a discharge takes place between the knobs R and S.

There is usually sufficient charge on one of the inductors to start the machine, but in damp weather it will often be found necessary to apply a

charge to one of the inductors by means of the ebonite or glass rod before the machine will work.

The Wimshurst Machine.—The essential parts of an ordinary Wimshurst machine, as shown in fig. 85, ***are two insulating plates or drums.***

On each plate are fixed a large number of strips of conducting material, which are equal in size and are equally spaced; these

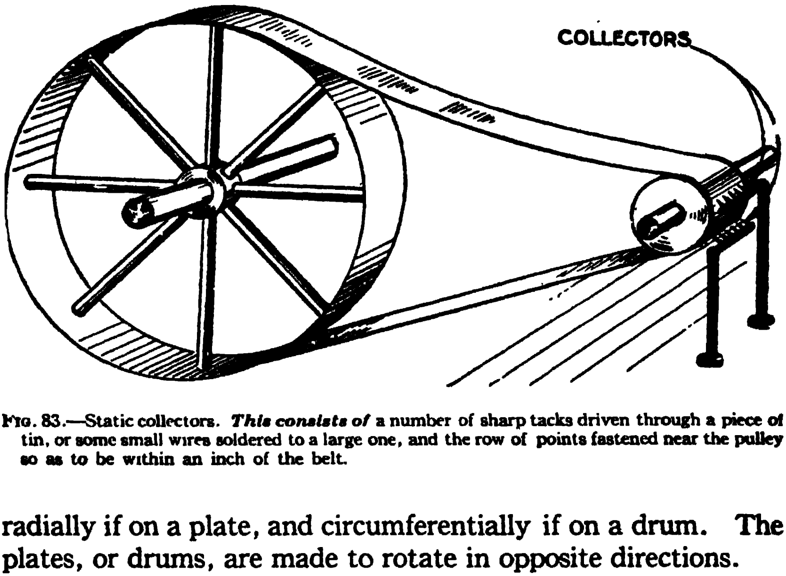
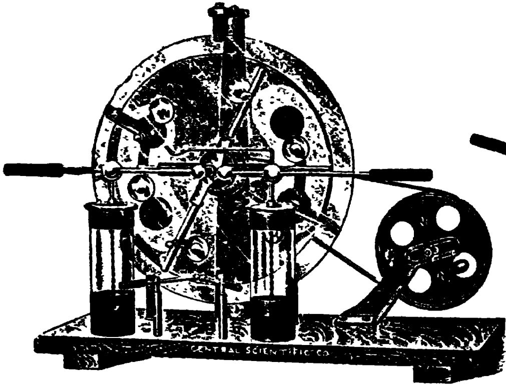


FIG. 83.—Static collectors. ***This consists of*** a number of sharp tacks driven through a piece of tin, or some small wires soldered to a large one, and the row of points fastened near the pulley so as to be within an inch of the belt.

radially if on a plate, and circumferentially if on a drum. The plates, or drums, are made to rotate in opposite directions.

The capacity of the inductors therefore varies from a maximum when each strip on one plate is facing a strip on the other, to a minimum when the conducting strips on each plate are facing blank or insulating portions of the other plate.

There are three pairs of contact brushes, the members of two of the pairs being at opposite ends of diametrical conducting rods placed at



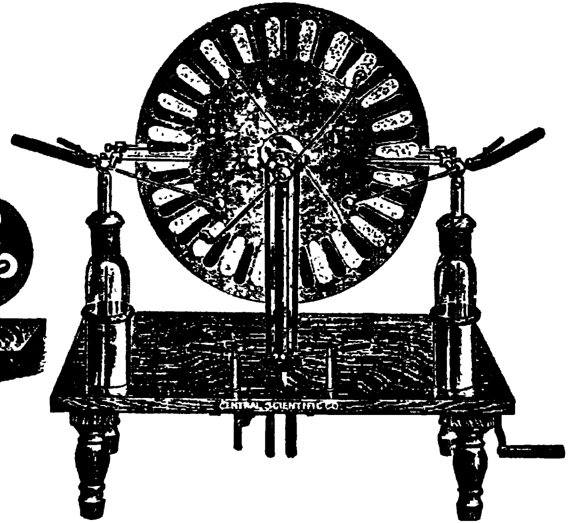


FIG. 84.—Mars Toepler-Holtz electric machine. ***In construction***, the belt tension is adjustable, the brushes are made of tinsel, which is claimed to be superior to wire. The condensers are of the Leyden jar type. There is a current breaker which permits the intensity and rate of discharge to be varied. The machine is equipped with a pair of nickel plated shocking handles and chain, and an attachment for holding accessories such as bell chimes, image plates, etc. A 3 to 6 inch spark may be produced, depending upon weather conditions. Revolving plate 12 in.; stationary plate 14 in.

FIG. 85.—Wimshurst self-charging static machine, new design. The machine works without change of poles, and is accordingly more satisfactory than the Toepler-Holtz type in which the poles may reverse at any moment. For this reason it is especially adapted to X-ray work. The machine is provide. with a spark gap attachment, and there is a current breaker, by means of which the outer coils of the Leyden jar may be either connected or disconnected, thus allowing either an intermittent spark discharge or a continuous discharge. Spark range from ¼ to ⅓ the plates diameter.

right angles to one another; the third pair are insulated from one another and form the principal collectors, the one giving positive and the other negative electricity.

The plates are revolving in opposite directions; thus if there be a charge on one of the conducting segments of one plate and an opposite charge on one of the conducting segments on the other plate near it, their pressure will be raised as the rotation of the plates separates them.

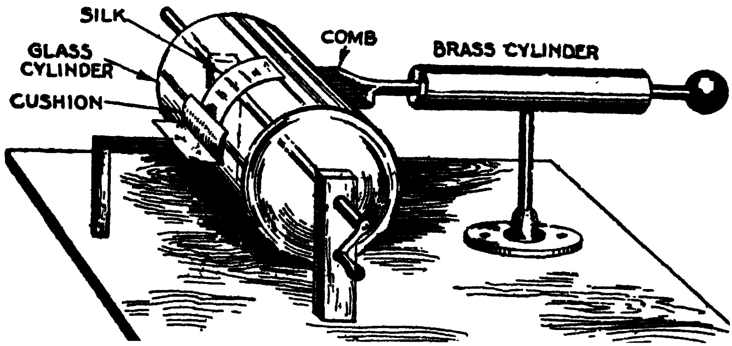


FIG. 86.—Electric form of friction machine. *In construction and operation,* a glass cylinder revolves around its axis which is turned by means of one or two wooden handles. On one side there is a leather cushion covered with amalgam of zinc or tin pressing against it, and a piece of silk extending from this cushion covers the upper part of the cylinder. On the other side there stands a brass cylinder, with a rod extending toward the glass cylinder and provided with sharp points (like a comb).

NOTE.—*Mascart* has shown the interesting fact that the Holtz machine is reversible in its action; that is to say, that if a continuous supply of the two electricities (furnished by another machine) be communicated to the armatures, the movable plate will be thereby set in rotation, and will turn in an opposite sense.

NOTE.—*Righi* has shown that a Holtz machine can yield a continuous current like a voltaic battery, the strength of the current being nearly proportional to the velocity of rotation. It was found that the electromotive force of a machine was equal to that of 52,000 Daniell's cells, or nearly 53,000 volts, at all speeds. The resistance, when the machine made 120 revolutions per minute was 2180 million ohms; but only 646 million ohms when making 450 revolutions per minute.

NOTE.—*The friction of a jet of steam* issuing from a boiler, through a wooden nozzle, generates electricity. In reality it is the particles of condensed water in the jet which are directly concerned.

TEST OUESTIONS

1. *What is static electricity?*
2. *How is it produced?*
3. *Explain electrical attraction and repulsion.*
4. *When are bodies said to be electrified?*
5. *What is the difference between positive and negative electricity?*
6. *How did Franklin class static electricity?*
7. *On what does frictional electricity depend?*
8. *Give Franklin's classified list.*
9. *What is understood by the term "charge"?*
10. *What happens when oppositely discharged bodies are brought into contact with each other?*
11. *How is a charged body discharged?*
12. *How is the charge distributed?*
13. *Describe Boit's experiment.*
14. *What is the effect of points?*
15. *Describe the electric wind mill.*
16. *What is the difference between free and bound electricity?*
17. *What is the difference between a conductor and an insulator?*
18. *What word is commonly, yet erroneously used for insulator? Why?*

19. *What is an electroscope?*
20. *What is an electroscope used for?*
21. *What happens when an electrified body is held near an electroscope?*
22. *Describe the gold leaf electroscope, naming its inventor.*
23. *Why are gold leaves used in the gold leaf electroscope rather than thinnest tissue paper?*
24. *Give method of using the gold leaf electroscope.*
25. *What is an electric screen?*
26. *Describe Faraday's electric screen experiment.*
27. *Explain electrification by induction.*
28. *Describe an experiment illustrating electrification by induction.*
29. *What is the nature of an induced charge?*
30. *What is an electrophorus and who invented it?*
31. *Explain how to use an electrophorus.*
32. *State the theory of the electrophorus.*
33. *What is a condenser?*
34. *What form of condenser is generally used for static electricity experiments?*
35. *Describe the Leyden jar.*
36. *How is the jar charged? Discharged?*
37. *What is an electric machine?*

38. *Describe the Toepler-Holtz machine.*

39. *What is the action of the Toepler-Holtz machine?*

40. *Describe the Wimshurst machine.*

41. *How does it operate?*

CHAPTER 3

Ohm's Law

The ordinary statement that *an electric current is flowing along a wire* is only a conventional way of expressing the fact that the wire and the space around the wire are in a different state from that in which they are when no electric current is said to be flowing.

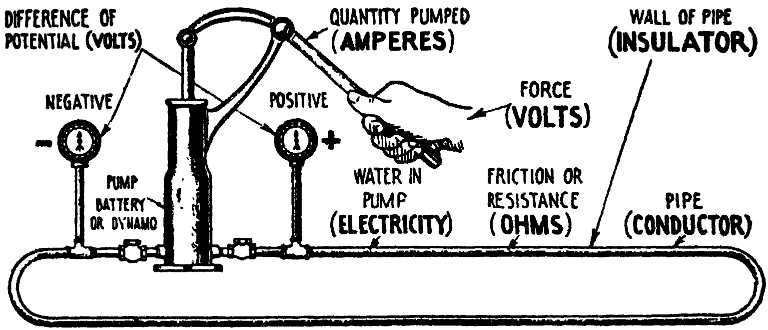


FIG. 87.—Hydraulic analogy of electric current.

In order to make laymen understand the action of this so-called current, it is generally compared with the flow of water.

In comparing hydraulics and electricity, it must be borne in mind, however, that there is really no such thing as an "electric fluid," and that water in pipes has mass and weight, while electricity has none. It should be noted, however, that elec-

tricity is conveniently spoken of as having weight in explaining some of the ways in which it manifests itself.

All electrical machines and batteries are merely instruments for moving electricity from one place to another, or for causing electricity, when accumulated in one place, to do work in returning to its former level of distribution.

The *head* or *pressure* in a standpipe is what causes water to move through the pipes which offer *resistance* to the *flow*.

Similarly, the conductors, along which the electric current is said to flow, offer more or less *resistance* to the flow, depending on the material. Coppei wire is generally used as it offers little resistance.

The current must have pressure to overcome the resistance of the conductor. This pressure is called *voltage* caused by what is known as *differenct of potential*, better called *difference of pressure*, between the source and terminal.

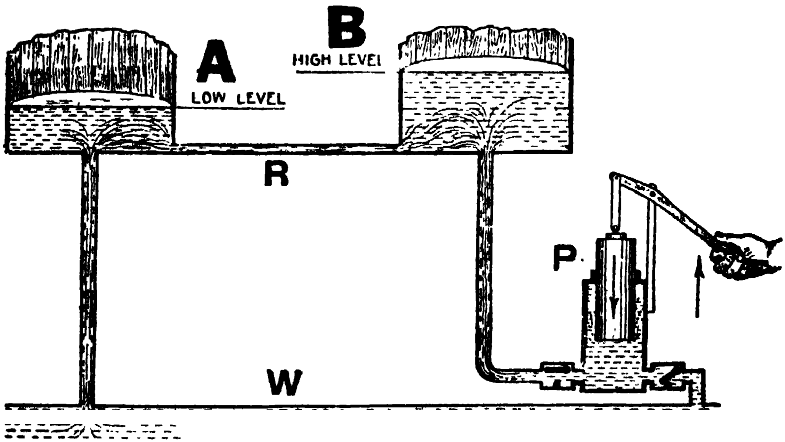
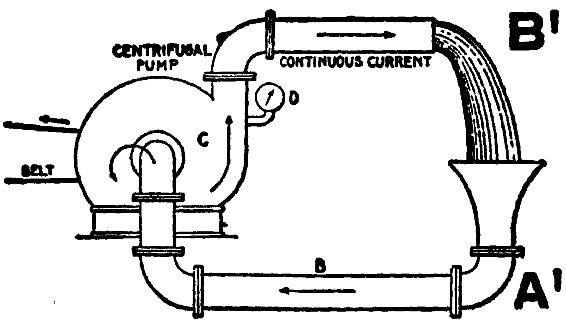


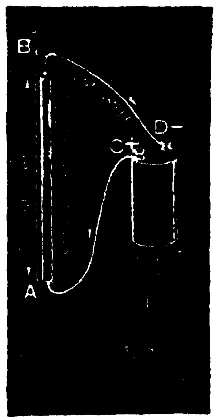
FIG. 88.—Analogy of the flow of water to the electric current. The water in the reservoirs A and B, stands at *different heights*. As long as this difference of level is maintained, water from B, will flow through the pipe R, to A. If by means of a pump P, the level in B, be kept constant, flow through R, will also be maintained. Here, by means of *the work expended on the pump*, the level in the reservoir is kept constant; and in the corresponding case of the electric current, by the conversion of chemical energy, or expenditure of energy on a dynamo or alternator, a constant difference of pressure is maintained.

The pressure under which a current flows is measured in *volts* and the quantity that passes in *amperes*. The resistance with which the current meets in flowing along a conductor is measured in *ohms*.

Ques. What is an ampere?

Ans. The ampere is a measurement of electric current flowing in a circuit. By definition, an ampere is the current produced when a pressure of one volt is impressed upon a circuit having a resistance of one ohm. An ampere is also defined as





FIGS. 89 and 90.—Diagrams showing hydraulic analogy illustrating the difference between amperes and coulombs. If the current strength in fig. 90 be one ampere, the quantity of electricity passing any point in the circuit per hour is $1 \times 60 \times 60 = 3{,}600$ coulombs. The *rate* of current flow of one ampere in fig. 90 may be compared to the rate of discharge of a pump as in fig. 89. Assuming the pump to be of such size that it discharges a gallon per revolution and makes 60 revolutions per minute, the quantity of water discharged per hour (coulombs in fig. 90) is $1 \times 60 \times 60 = 3{,}600$ gallons. Following, the analogy further (in fig. 90), the pressure of one volt is required to force the electricity through the resistance of one ohm between the terminals A and B. In fig. 89, the belt must deliver sufficient power to the pump to overcome the friction (resistance), offered by the pipe and raise the water from the lower level A', to the higher level B'. The difference of pressure between A and B, in the electric circuit corresponds to the difference of pressure between A' and B'. The cell furnishes the energy to move the current by maintaining a difference of 1 at its terminals C and D; similarly, the belt delivers energy to raise the water.

that unvarying current which when passed through a solution of nitrate of silver in water in accordance with certain specifications, deposits silver at the rate of 1.118 milligrams per second.

Ques. What is a coulomb?

Ans. The quantity of electricity delivered by a current of one ampere maintained for one second of time. In other words one coulomb equals one ampere-second.

Ques. What is a volt?

Ans. A *volt* is that electromotive force (e.m.f.) or pressure which produces a current of *one ampere* when steadily applied to a conductor, the resistance of which is *one ohm.*

The two main sources of electromotive force are primary batteries and electric generators. Primary cells consist essentially of two dissimilar metallic conductors immersed in an electrolyte, the combinations of which transform chemical energy directly into electrical energy.

An electric generator on the other hand, produces an electromotive force through the relative motion between a magnetic field and an electric conductor. The magnetic field may be stationary and the conductor moving or the conductor may be stationary and the magnetic field moving.

The strength of the initial electromotive force is determined by the battery or generator used, but the current that results depends also on the resistance of the circuit. If the resistance of the circuit be great, even though the initial voltage be high, the current will be small. If, on the other hand, the resistance be small, the current may be large, even though the voltage be low.

Ques. What is resistance?

Ans. Resistance may be defined as that property of a substance that opposes the flow of an electric current through it. The unit for the measurement of this resistance or opposition to the flow of current through it, is called the *ohm**.

*NOTE.—The unit of resistance is termed the *ohm* in honor of the Ge *George Simon Ohm* who first discovered the relation called *Ohm's law,* which gives a mathematical relationship between the current, electromotive force and the resistance of an electric circuit.

The standard ***ohm*** is the resistance of a column of mercury 106.3 centimeters in length and one square millimeter in cross-section.

The unit for the measurement of very low resistance is the ***microhm*** and is equal to one millionth of an ohm; the unit for very high resistance is the ***megohm*** and is equal to one million ohms.

The resistance of a conductor is determined by the type of material of which it is made up, and also by the form (length and cross-section) of the various portions of the circuit. Thus, the resistance of a conductor varies directly as its length and inversely as its area; that is, the greater the length, the greater the resistance, and the greater the area, or cross-section, the smaller the resistance.

Gold, silver, copper and aluminum are the best conductors; zinc, iron and tin are fair; platinum, German silver, mercury and carbon are poor. Copper is particularly adapted for conductors on account of its high conductivity, its abundance and the ease with which it is worked into various shapes.

The resistance of a material also changes with the temperature. For metals the resistance increases with the temperature. Many metals if cooled to near the absolute zero of temperature ($-273°$ C.) becomes super-conductors.

Since the resistance of a conductor varies directly with the length and inversely as its cross-sectional area, the general formula for the resistance would be:

$$R = \frac{\rho \times L}{A}$$

Where R = resistance in ohms.

L = length in feet.

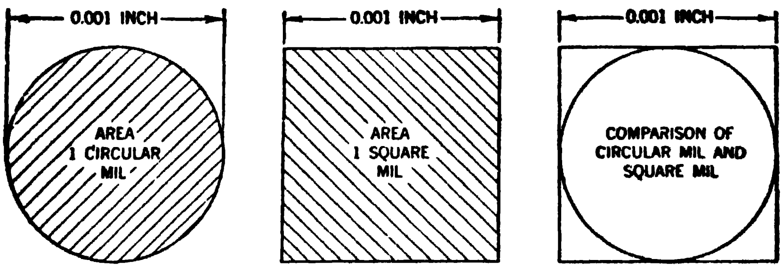
A = area in circular mils.

ρ = specific resistance (10.4 to 10.8 for copper, depending on temperature).

Ques. What is a circular mil?

Ans. The circular mil is the unit of cross-section used in the American wire gauge. The mil is a linear measure and is equal to 0.001 of an inch. Thus if a round wire has a diameter of one mil, then the area of cross-section of that wire is one circular mil.

Since the area of conductor varies as the square of its circular dimension, the area of any circle can be expressed in circular mils by squaring its diameter expressed in thousandths. Thus since $5/8 = 625/1000 = 0.625$ the area of a circle $5/8$ in. in diameter would be $625 \times 625 = 390{,}625$ circular mils. Similarly the area of a circle 0.005 in. in diameter would be 5×5 or 25 circular mils.



FIGS. 91 to 93.—Enlarged view of circular mil and square mil. FIG. 93 indicates relative size of the two units.

Ques. What is a square mil?

Ans. The square mil is the area of a square each side of which is one mil (0.001 inch). The number of circular mils multiplied by $\pi/4$ or 0.7854 gives the number of square mils; and conversely the number of square mils multiplied by $4/\pi$ or 1.273 gives the number of circular mils.

The foregoing relations may be written as follows:

$$\textit{Square mils} = \textit{circular mils} \times 0.7854$$

$$\textit{Circular mils} = \frac{\textit{square mils}}{0.7854}$$

Thus, any circular conductor may easily be converted into a rectangular conductor (bus bar for example) containing the same area or current carrying capacity.

Ques. What is a circular mil-foot?

Ans. *The mil foot is a unit circular conductor one foot in length and one mil in diameter.* The resistance of such a unit of copper has been found to be approximately 10.4 *ohms* at ordinary room temperature. *This value is important* and should be remembered because from this the resistance of copper conductors of any cross-section and length may easily be calculated.

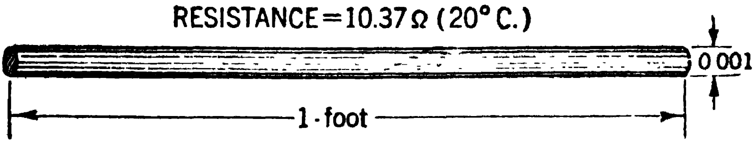


FIG. 94.—Illustrating *dimensions* and *resistance* of a circular mil foot of copper.

Ques. How may the resistance of a conductor of any common metal or alloy be obtained?

Ans. By using the resistance value (ρ) for one circular mil-foot of the metal or alloy in question (usually obtained from engineering handbooks) and by substitution in the following formula:

$$R = \frac{\rho \times L}{\text{cir. mils.}} \text{ or}$$

$$R : \rho \times L$$

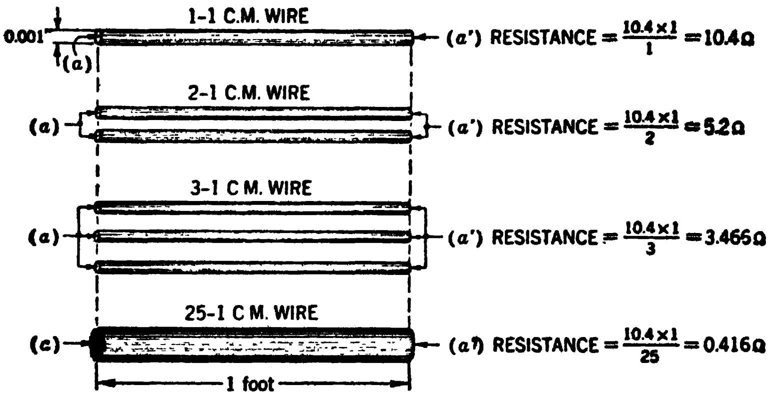
Where R = resistance of the conductor in ohms.

ρ = resistance of a cir. mil. ft. of the material composing the conductor.

L = length of the conductor in feet.

d = diameter in mils.

d^2 = diameter in mils squared, or what is the same thing, the area of the conductor in circular mils.



FIGS. 95 to 98.—Illustrating how the resistance of a conductor decreases with an increase of the area through which the current flows. Fig 95 indicates the ohmic resistance between terminals *a-a'* when one circular mil-foot be employed; figs. 96 and 97 indicates how the resistance between terminals *a-a'* decreases when the same conductors are connected in parallel; fig. 98, shows resistance between terminals *a-a'* when 25 one circular mil conductors are bundled together. The resistance in this latter case is only 1/25th of that of the single conductor. Thus, any wire may be thought of as composed of a bundle of wires, each, one circular mil in cross-section bound together. The number of circular mils in a given wire is then the number of circular mil wires required to make up the cross-section in question.

Ohm's Law.—When a current flows in any electric circuit, the magnitude of the current is determined by the electromotive force in the circuit and the resistance of the circuit, the resistance being dependent on the material, cross-section, and length of the conductor.

The relation which determines the amount of current flowing through a circuit is known as *Ohm's law*. It is a very simple law, but is of such great value that it should be studied with particular care. It should be thoroughly memorized by every student of electricity, because by means of it, the majority of problems of electric circuits can be solved.

Ohm's law states that in a given circuit the amount of current in amperes is equal to the pressure in volts, divided by the resistance in ohms, that is:

$$\text{current} = \frac{\text{pressure}}{\text{resistance}} = \frac{\text{volts}}{\text{ohms}}$$

which, if expressed by symbols, becomes:

$$I = \frac{E}{R} \text{ or } R = \frac{E}{I} \text{ or } E = IR$$

Where I = current flow in amperes.
E = pressure in volts.
R = resistance in ohms.

In the form as thus written, **Ohm's law** applies only to direct current circuits or non-inductive alternating current circuits.

Voltage Drop in an Electric Circuit.—A difference of pressure exists between any two points on a conductor through which current is flowing on account of the resistance offered to the current by the conductor. Thus, when an electric current is used at a considerable distance from the generator, the voltage at the receiving end of the line is always less than the generator voltage. This *voltage drop in the line* is equal to the current times the resistance of the line (IR). The voltage drop for ordinary incandescent lamps should not exceed three per cent.

In motor circuits a three per cent drop is considered good practice, but should under no conditions exceed that recommended by the *National Electric Code.*

The per cent line drop or voltage loss may be calculated either as a percentage of the voltage required at the receiver or as a percentage of the line voltage impressed by the generator or other energy source on the line.

Thus, for example, in fig. 99, the voltage impressed on the receiver (motor and lamps) is 110 volts. The line loss is 3 volts, hence the pressure impressed on the line is $110+3=113$ volts. The voltage loss as a percentage of the voltage at the receiver $=3/110=0.0273=2.73$ per cent. The voltage loss as a percentage of the voltage impressed upon the line is $3/113=0.0265=2.65$ per cent.

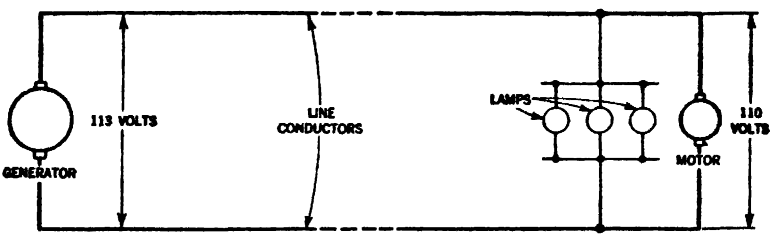


FIG. 99.—Illustrating method of voltage drop calculation in a simple direct current circuit.

In practical work the percentage loss or drop is usually taken as a percentage of the voltage required at the receiver because this is the most convenient and direct method.

Series and Parallel Connections.—Resistance, like cells, may be connected in series, in parallel or in series-parallel. When two or more resistors are connected in series, the total resistance of the group is higher than that of each individual resistor. When, on the other hand, two or more resistors are connected in parallel the total resistance is decreased.

A series resistance may be defined as one in which the resistances are connected in a continuous run (e.i., connected end to end) as shown in fig. 100. It is evident that since the circuit has no branches, the same current flows in each resistance.

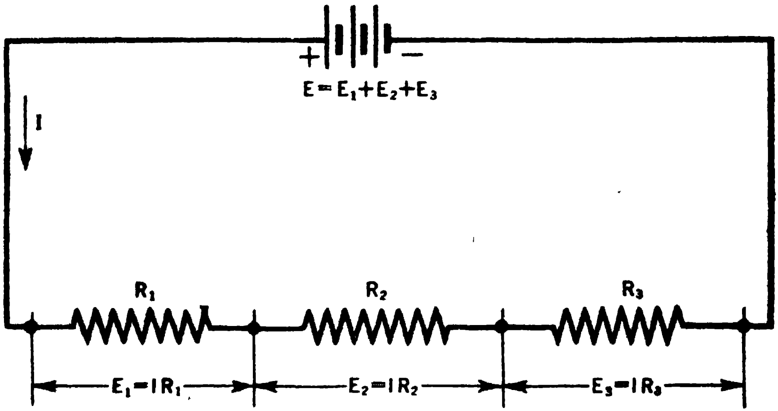


FIG 100.—Illustrating a circuit having three resistances connected in series.

The total potential drop across the whole circuit equals the potential drop due to each individual resistance, or

$$E_1 = IR_1$$
$$E_2 = IR_2$$
$$E_3 = IR_3$$
$$\text{Since } E = E_1 + E_2 + E_3$$
$$\text{and } R = R_1 + R_2 + R_3$$

The equation for the total potential of the circuit is:

$$E = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$$

$$\text{and } I = \frac{E}{R_1 + R_2 + R_3} = \frac{E}{R}$$

If a number of equal resistances are connected in series, we may write for the equivalent resistance of the group

$$R = nr$$

Where n is the number and r is the resistance of each.

Parallel Connections.—If several resistances be connected as shown in fig. 101, so that only a part of the current passes through each resistance, they are said to be connected in **parallel** or **multiple.** The pressure E between points a and b is the same over any branch.

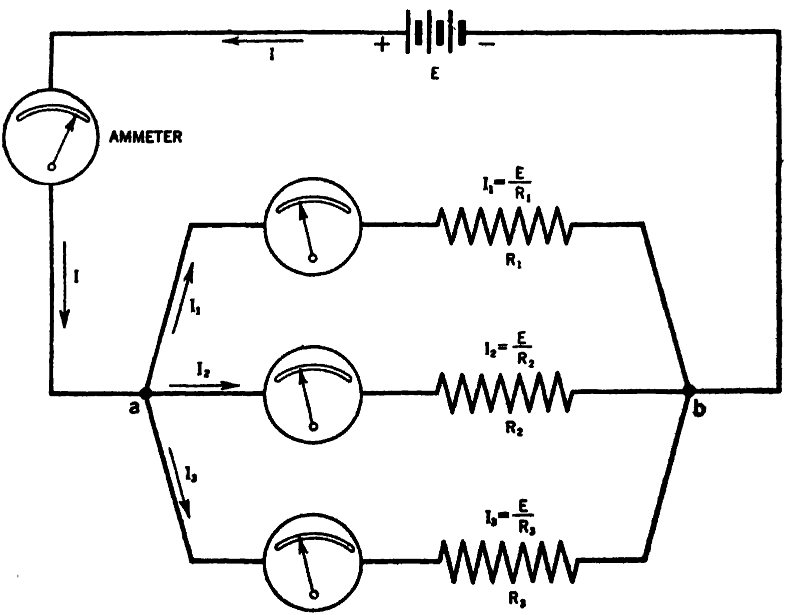


FIG. 101.—Illustrating a circuit having three resistances connected in parallel.

We may then write:

$$E = I_1R_1 = I_2R_2 = I_3R_3$$

and

$$I = I_1 + I_2 + I_3$$

When Ohm's law is applied to the individual resistances, the following equations are obtained:

$$I_1 = \frac{E}{R_1};\ I_2 = \frac{E}{R_2} \text{ and } I_3 = \frac{E}{R_3}$$

$$\text{Hence } I = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} \text{ or}$$

$$I = E\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

but since $I = \frac{E}{R}$, the equivalent resistance R of the several resistances connected in parallel becomes:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The value $1/R$ is expressed as the conductance of the circuit; its unit is *mho*, and is usually expressed by g or G.

It is written

$$g = \frac{1}{R}$$

When there are only two resistances connected in parallel

$$R = \frac{R_1R_2}{R_1 + R_2} \text{ ohms}$$

Thus the two resistances in parallel have a joint or equivalent resistance, given by the product of the resistance divided by their sum.

If there be three resistances connected in parallel

$$R = \frac{R_1R_2R_3}{R_1R_2+R_1R_3+R_2R_3} \text{ ohms}$$

The conductance of this circuit is

$$g = \frac{1}{R} = \frac{R_1R_2+R_1R_3+R_2R_3}{R_1R_2R_3} \text{ mhos}$$

When there are a large number of single resistances, all of the same value, it can be shown that the joint resistance of the group is given by

$$R = \frac{r}{n}$$

Where r = value of one resistance.

n = number of resistances.

When resistances are connected in parallel, it must be remembered that the voltage across the several resistances is constant, and that the total current is subdivided among the several branches.

Series-Parallel Connections.—The most common arrangement of conductors in an electrical circuit is a combination of the series and parallel circuit such as that shown in fig. 102.

The resistance from *a* to *b* of such a circuit is the sum of all the resistances of the several parts. Thus the resistance from *a* to *b* is equal to the resistance from *a* to *c* plus that from *c* to *d* plus that from *d* to *b*. The total resistance of the circuit is, therefore,

$$R = R_1 + \frac{R_2R_3R_4}{R_2R_3 + R_2R_4 + R_3R_4} + R_5$$

The main thing to remember when dealing with series-parallel combinations of resistance is to reduce each parallel group into its equivalent resistance, and then add up the result to obtain the total resistance of the circuit.

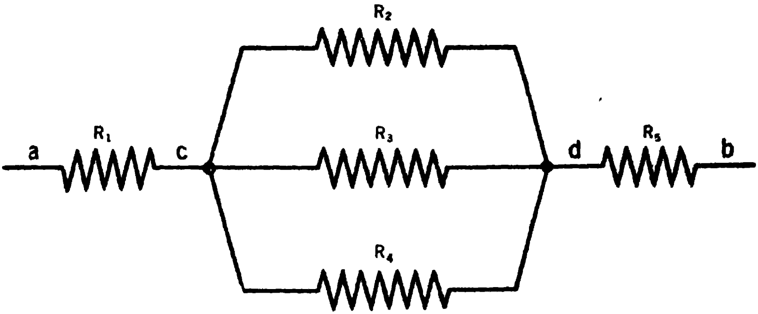


FIG 102.—Illustrating how the joint resistances of a series-parallel branch may be calculated.

Batteries in Series and Parallel.—It is frequently necessary when using batteries to increase the effect which a single cell can produce. This is done by connecting the cells in any one of three ways, namely:

1. ***In series.***—Here the + side of one cell is connected to the − side of the next one, and so on for all the cells as shown in fig. 103.

2. ***In parallel.***—In this case all the + terminals are connected together and all the − terminals are connected together as shown in fig. 104.

3. ***In a combination of series and parallel groups.***—Several groups of cells in series may be connected in parallel, as in fig. 105, or several groups of cells in parallel may be connected in series, as in fig. 106.

The proper combination to use in any given case is dependent upon circumstances, but in general a series arrangement builds

up voltage, but at the same time it increases the internal resistance, while a parallel arrangement by decreasing the internal resistance permits greater current to flow. If the number of cells be represented by n, the e.m.f. of each cell by E, the internal resistance of one cell by r, and the external resistance by R, we may write Ohm's law for each of the foregoing cases.

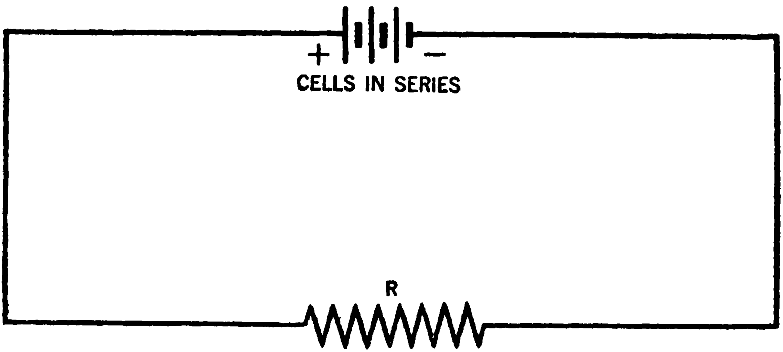


FIG. 103.—Illustrating circuit arrangement with cells connected in series.

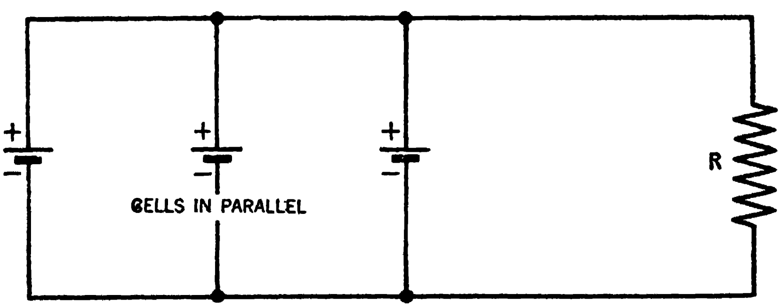


FIG. 104.—Circuit arrangement with cells connected in parallel.

For series arrangement,

$$I=\frac{nE}{R+nr}$$

For parallel arrangement,

$$I=\frac{E}{R+r/n}$$

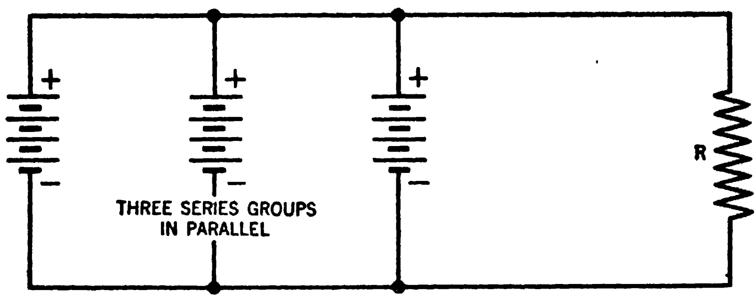


FIG. 105.—Circuit arrangement with three series groups of cells connected in parallel.

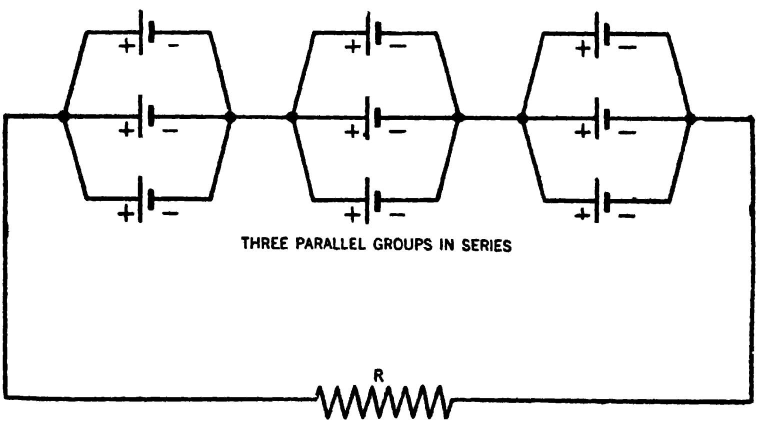


FIG. 106.—Circuit arrangement with three parallel groups of cells connected in series.

For n cells in series in each group, and m such groups in parallel,

$$I = \frac{nE}{R + nr/m}$$

If it be desired to build up a large current through R with a given number of dry cells, especially when their internal resistance has become relatively large through age, a series arrangement may actually cause the internal resistance to increase faster than the voltage. Hence, adding cells in series would result in a decrease of current. The best use of a given number of cells to produce a stated current, under fixed external circuit resistance, can only be determined by a careful application of *Ohm's law* and the previous equations, having the entire circuit in mind.

In general the largest current from a given number of cells will be obtained when they are so grouped that the internal resistance of the battery is equal to the external resistance of the circuit.

Batteries will be connected in series when the external resistance is large, and in parallel when the external resistance is small. In lighting systems, with many incandescent lamps in parallel, the lamp resistance is large compared to the line resistance, and very nearly the full voltage is realized at the lamp socket.

Power in Direct Current Circuits.—Power is the rate of transfer of energy. One watt is produced when one ampere flows under a pressure of one volt. It is written:

$$P = EI$$

Where P = power in watts.

E = pressure in volts.

I = current in amperes.

If the resistance in the circuit be known we may substitute E for its equivalent IR and obtain

$$P = I^2R$$

or we may substitute I for its equivalent E/R and obtain

$$P = \frac{E^2}{R}$$

In a similar manner we obtain

$$I = \frac{P}{E} = \sqrt{\frac{P}{R}} \text{ and}$$

$$E = \frac{P}{I} = \sqrt{PR}$$

$$\text{or} \quad R = \frac{E^2}{P} = \frac{P}{I^2}$$

Watts, Kilowatts and Horsepower.—These are the common units used in power measurements. They differ from one another only in their size. Thus one horsepower equals 746 watts; therefore:

$$HP = \frac{\text{watts}}{746} = \text{watts} \times 0.00134, \text{ also}$$

$$\text{watts} = HP \times 746, \text{ and}$$

$$KW = HP \times 0.746$$

$$HP = \frac{KW}{0.746} = KW \times 1.34$$

Ohm's Law Calculations

Example.—Three resistances, fig. 106-1 of 16, 30 and 50 ohms, respectively, are connected in series across a 120 volt source. Calculate (a) the current flow and (b) the voltage drop across each resistor.

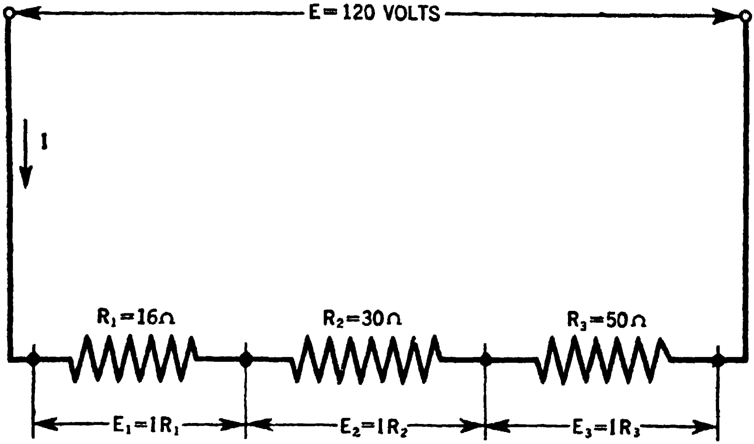


FIG 106-1.—Circuit with three resistances connected in series.

Solution.—The total resistance of the circuit is the sum of these resistances, or 16+30+50=96 ohms When connected across a 120 volt line, the current according to Ohm's law is:

(*a*) $$I = \frac{E}{R} = \frac{120}{96} = 1.25 \text{ amp.}$$

(*b*) The voltage drop across the 16 ohm resistance is:

$$E_1 = IR_1 = 1.25 \times 16 = 20 \text{ volts.}$$

The voltage drop across the 30 ohm resistance is.

$$E_2 = IR_2 = 1.25 \times 30 = 37.5 \text{ volts.}$$

Finally, the voltage drop across the 50 ohm resistance is:

$$E_3 = IR_3 = 1.25 \times 50 = 62.5 \text{ volts.}$$

The total voltage is the sum of these separate drops or **20+37.5+62.5=120 volts.**

Example.—If the resistances in the previous example were all connected in parallel, what would the total current and the current in each individual resistor be, assuming the impressed voltage at 120 as before?

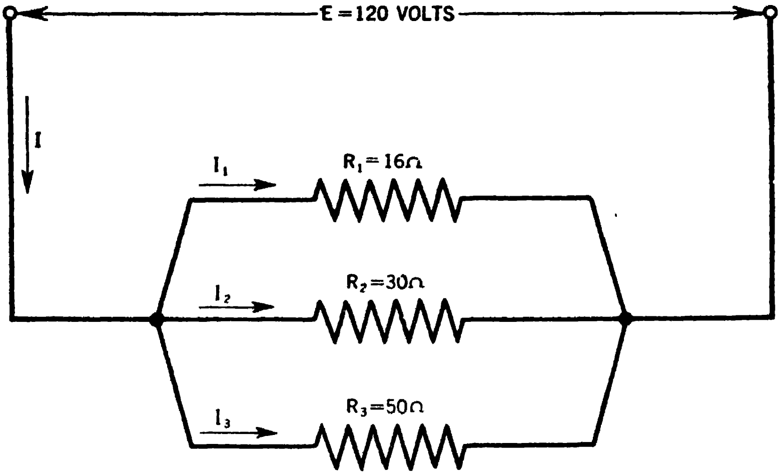


FIG. 106-2.—Circuit with three resistances connected in parallel

Solution.—With the resistances in parallel, the joint resistance of the parallel branch is:

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{16}+\frac{1}{30}+\frac{1}{50}=\frac{69.5}{600}$$

and $$R=\frac{600}{69.5}=8.63\text{ ohms.}$$

The total current $$I=\frac{120}{8.63}=13.9\text{ amperes.}$$

The branch currents are, respectively:

$$I_1=\frac{E}{R_1}=\frac{120}{16}=7.5\text{ amperes}$$

$$I_2=\frac{E}{R_2}=\frac{120}{30}=4.0\text{ amperes}$$

$$I_3 = \frac{E}{R_3} = \frac{120}{50} = 2.4 \text{ amperes}$$

Example.—A current of 42 amperes flows in a circuit, fig. 106-3, and divides into three parts in the three branches of resistance 5, 10 and 20 ohms, respectively.

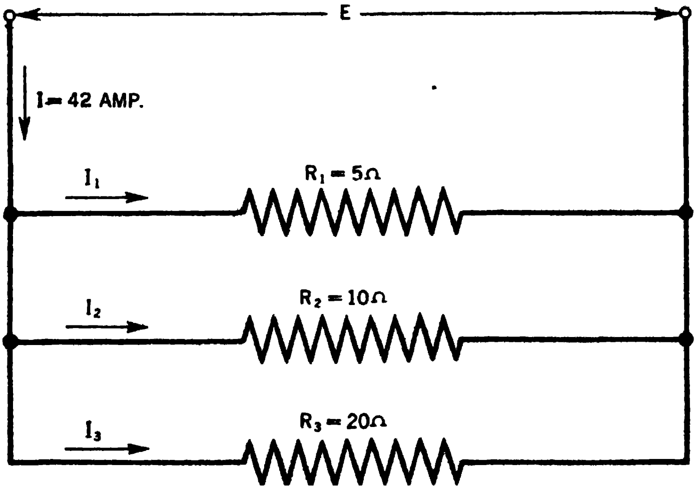


Fig. 106-3 —Circuit with three resistances connected in parallel

Calculate.—

(*a*) The total or joint resistance.

(*b*) The voltage drop across the circuit.

(*c*) The current in each branch of the circuit.

(*d*) The power absorbed in each resistance.

(*e*) The total power absorbed

Solution.—The resistance of the parallel combination is:

$$\frac{1}{R} = \frac{1}{5} + \frac{1}{10} + \frac{1}{20} = \frac{7}{20}$$

(*a*) $$R = \frac{20}{7} = 2.86 \text{ ohms}$$

(*b*) The voltage drop

$$E=\frac{20}{7}\times 42=120 \text{ volts}$$

(*c*) The several currents may be calculated from Ohm's law, as follows:

$$I_1=\frac{120}{5}=24 \text{ amperes}$$

$$I_2=\frac{120}{10}=12 \text{ amperes}$$

$$I_3=\frac{120}{20}=6 \text{ amperes}$$

(*d*) The power absorbed in each resistance is as follows:

$$P_1=I_1^2R_1=24^2\times 5 \ \ =2.88 \ kw.$$

$$P_2=I_2^2R_2=12^2\times 10=1.44 \ kw.$$

$$P_3=I_3^2R_3= \ 6^2\times 20=0.72 \ kw.$$

(3) The total power absorbed in the circuit is the sum of that absorbed in the individual branches, or $2.88+1.44\times 0.72=5.04$ *kw*.

By another use of Ohm's law the foregoing result may be used as a check. We have

$$P=EI=120\times 42=5040 \text{ } watts \text{ or } 5.04 \ kw.$$

as before.

Example.—What is the joint resistance of two resistances of 6 and 12 ohms, respectively, when connected in parallel?

Solution.—Substituting in the formula for parallel resistors, we have:

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}=\frac{1}{6}+\frac{1}{12}=\frac{3}{12}$$

It follows that

$$R=\frac{12}{3}=4 \text{ ohms}$$

Example.—What is the equivalent resistance of a circuit in which there are three resistances in parallel, consisting of 5, 10 and 12.5 ohms, respectively?

Solution.—By formula, we obtain

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{5}+\frac{1}{10}+\frac{1}{12.5}=\frac{19}{50}$$

or

$$R=\frac{50}{19}=2.63 \text{ ohms}$$

Example.—Determine the equivalent resistance of circuits shown in figs. 106-4 to 106-7.

Solution.—Considering fig. 106-4 and using formula we obtain the equivalent resistance as:

$$R=20+\frac{150\times300}{150+300}=20+100 \text{ or } 120 \text{ ohms}$$

Circuit fig. 106-5 consists of two branches, with respect to its left hand branch we have its conductance:

$$\frac{1}{R}=\frac{1}{100}+\frac{1}{200}+\frac{1}{300}=0.01+0.005+0.00333=0.01833 \text{ mho.}$$

$$R=\frac{1}{0.01833}=54.54 \text{ ohms}$$

The conductance of the right hand branch is:

$$\frac{1}{R}=\frac{1}{400}+\frac{1}{500}=0.0025+0.002=0.0045 \text{ mho}$$

$$R=\frac{1}{0.0045}=222.22 \text{ ohms}$$

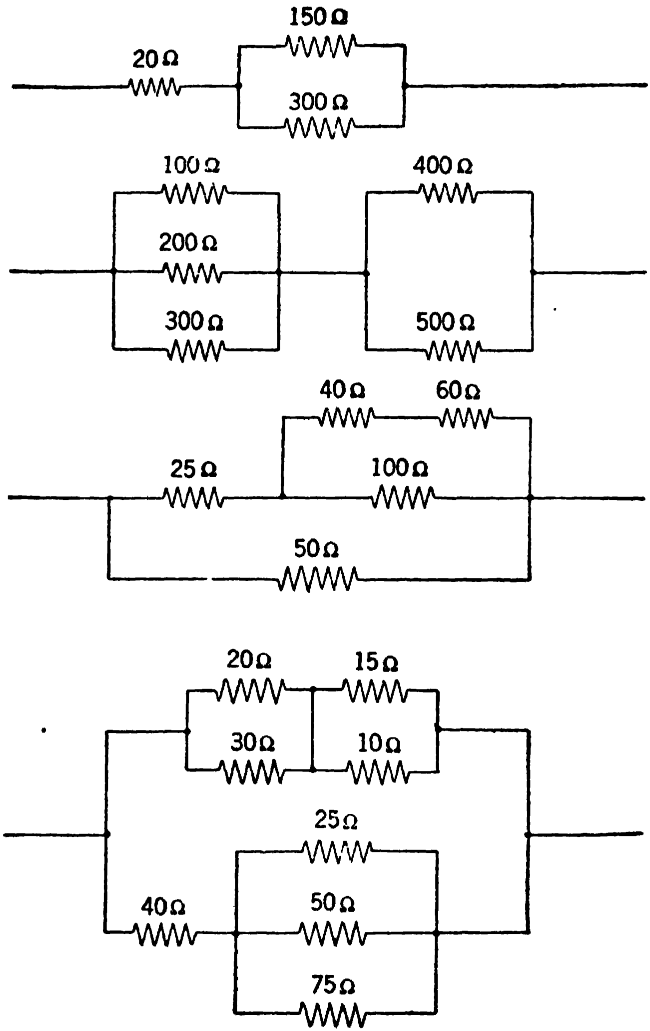
The total equivalent resistance of circuit fig. 106-5 is, therefore

$$54.54+222.22=276.76 \text{ ohms}$$

The equivalent resistance of circuit fig. 106-6 is calculated in a similar step by step method, that is, the innermost branch is first substituted for its equivalent resistance, after which the remaining parallel branch is calculated in the usual manner, thus when considering the 40, 60 and 100 ohms branch, we have:

$$\frac{1}{R}=\frac{1}{40+60}+\frac{1}{100}=0.02 \text{ mho}$$

$$R=\frac{1}{0.02}=50 \text{ ohms}$$



Figs. 106-4 to 106-7.—Various series-parallel and parallel connected resistances.

If the remainder of circuit be calculated as indicated its equivalent ohmic value will be found to equal 30 ohms.

The equivalent resistance of circuit fig. 106-7 may be found in a similar manner, considering the top branch we obtain for the 20-30 ohms circuit.

$$\frac{1}{R}=\frac{1}{20}+\frac{1}{30}=0.05+0.0333=0.0833 \text{ mho}$$

$$R=\frac{1}{0.0833}=12 \text{ ohms}$$

The equivalent resistance for the 15-10 ohms part is:

$$\frac{1}{R}=\frac{1}{15}+\frac{1}{10}=0.0667+0.1=0.1667 \text{ mho}$$

$$R=\frac{1}{0.1667}=6 \text{ ohms}$$

These equivalent resistances being in series, may now be added arithmetically, their value $=12+6=18$ ohms.

For the 25-50-75 ohms part of the circuit we have,

$$\frac{1}{R}=\frac{1}{25}+\frac{1}{50}+\frac{1}{75}=0.04+0.02+0\ 01333=0.07333 \text{ mho}$$

$$R=\frac{1}{0.07333}=13.64 \text{ ohms}$$

The circuit is now being reduced to two parallel branches, the upper part having a resistance of 18 ohms and the lower part a resistance of $40+13.64=53.64$ ohms, we finally obtain

$$\frac{1}{R}=\frac{1}{18}+\frac{1}{53.64}=0.0555+0.0187=0.0742 \text{ mho}$$

$$R=\frac{1}{0.0742}=13.48 \text{ ohms}$$

which is the equivalent resistance for the complete circuit.

Example.—If a group of lamps which takes 12 amperes are located 500 feet from the generator, and if the line drop must not exceed 2.6 volts, what size of copper wire must be used in the line wires?

Solution.—The resistance of the line wires according to Ohm's law is:

$$R=\frac{E}{I}=\frac{2.6}{12}=0.217 \text{ ohm}$$

We also have

$$R=\frac{\rho 2L}{A} \text{ and } A=\frac{\rho 2L}{R}=\frac{10.4\times2\times500}{0.217}=47{,}926 \text{ c.m.}$$

Example.—A wattmeter and an ammeter are connected in a direct current motor circuit. When the motor is running, the wattmeter reads 1,200 and the ammeter 9.5. What is the line voltage?

Solution.—Since watts are the product of the impressed voltage and the current flowing, we may write:

$$P=E\times I \text{ and } E=\frac{P}{I}=\frac{1{,}200}{9.5}=126 \text{ volts}$$

Example.—A motor takes 30 *kw.* from the line. How many horsepower is it taking?

Solution.—A substitution in our formula gives:

$$HP=\frac{KW}{0.746}=\frac{30}{0.746}=40.2\ hp.$$

Example.—The resistance of a certain voltmeter is 150,000 ohms. What is the power expended in the voltmeter when connected across a 120 volt line?

Solution.—By substituting in the formula for power.

$$P=\frac{E^2}{R}=\frac{120^2}{150{,}000}=0.096 \text{ watt}$$

Example.—In checking the power consumption of a direct current motor, the ammeter and voltmeter reading were 40.2 and 120, respectively. How many horsepower is it taking from the line?

Solution.—Substituting in the formula, we obtain:

$$HP=\frac{EI}{746}=\frac{40.2\times120}{746}=6.47\ hp.$$

Example.—What is the diameter in circular mil units of a wire whose cross-sectional area is 22,500 circular mils?

Solution.—The diameter of the wire in mils is:

$$d=\sqrt{22{,}500}=150$$

Example.—What is the resistance of a mile of copper wire 0.25 in. in diameter?

Solution.—The resistance (R) of the wire is

$$R=\frac{\rho L}{A}=\frac{10.4\times5{,}280}{250^2}=0.879 \text{ ohm}$$

Example.—What is the area of cross-section in circular mils of a round wire ¼ in. in diameter?

Solution.—Since the diameter of the wire equals 0.250 in. the cross-section in circular mils $=250^2=62{,}500$.

TEST QUESTIONS

1. *What is an electric current?*
2. *What should be noted in comparing hydraulics and electricity?*
3. *What is electric pressure called?*
4. *Define: Volt, ampere, ohm, circular mil.*
5. *State Ohm's law.*
6. *In what units are resistance, current, voltage and power measured?*
7. *What is the effect of temperature upon resistance?*
8. *What kind of metal is generally used in conductors of electricity?*
9. *Describe what is meant by the voltage drop in an electric circuit.*
10. *What formula is generally used in determination of joint or equivalent resistance of parallel circuits?*
11. *What is meant by the term "Conductance"?*
12. *How are a given number of cells usually connected to obtain (a) maximum voltage; (b) maximum current?*
13. *What are the relations between horsepower, watts and kilowatts?*
14. *How would you ascertain the amount of current drawn by 1,200 watt heating element, when connected to a 120 volt circuit?*

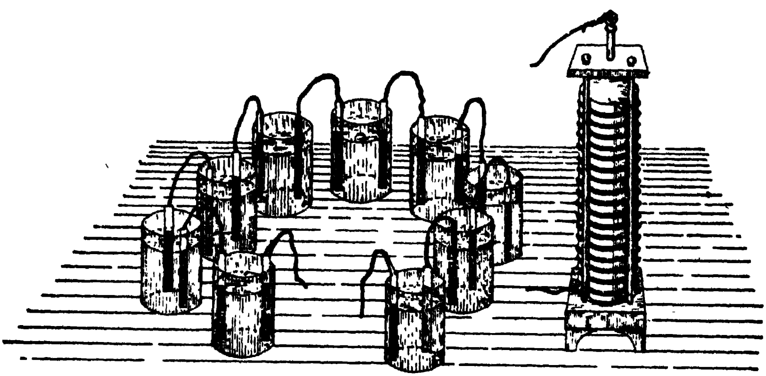
CHAPTER 4

Primary Cells

The word "battery" is a much abused word; being often used incorrectly for "cell," as in fig. 109. Hence, careful distinction should be made between the two terms.

A battery consists of two or more cells joined together so as to form a single unit.

There are numerous forms of primary cell; they may be classified as follows:



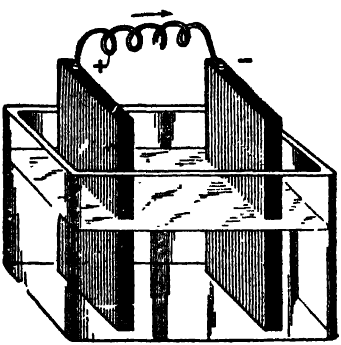
FIGS. 107 and 108.—Couronne de Tasses and Volta's pile, the first of all batteries (1800). The Couronne de Tasses (crown of cups) was a battery of simple cells in series. Each cell was composed of a plate of silver or copper and one of zinc immersed in brine. Volta's pile, fig. 108, consisted of a series of alternate discs of zinc and copper, separated by moistened felt. Surprising results were obtained with this pile.

1. According to the service for which they are designed;
2. According to the chemical features.

With respect to the first method, cells are classified as:

1. Open circuit cells;

Used for *intermittent work*, where the cell is in service for short periods of time, such as in electric bells, signaling work, and electric gas lighting. If kept in continuous service for any length of time the cell soon polarizes or "runs down," but will recuperate after remaining on open circuit for some little time.



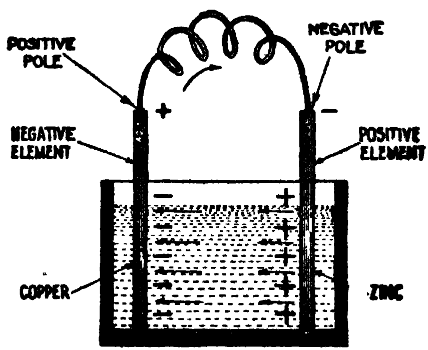


FIG. 109.—Simple primary cell. *It consists of* two dissimilar metal plates (such as copper and zinc which are called the *elements*) immersed in the electrolyte or exciting fluid contained in the glass jar.

FIG. 110.—Simple primary cell illustrating the terms poles and elements. *Carefully note that the negative element has a positive pole, and the positive element a negative pole.*

2. Closed circuit cells.

This type of cell is adapted to furnishing current continuously, as in telegraphy, etc.

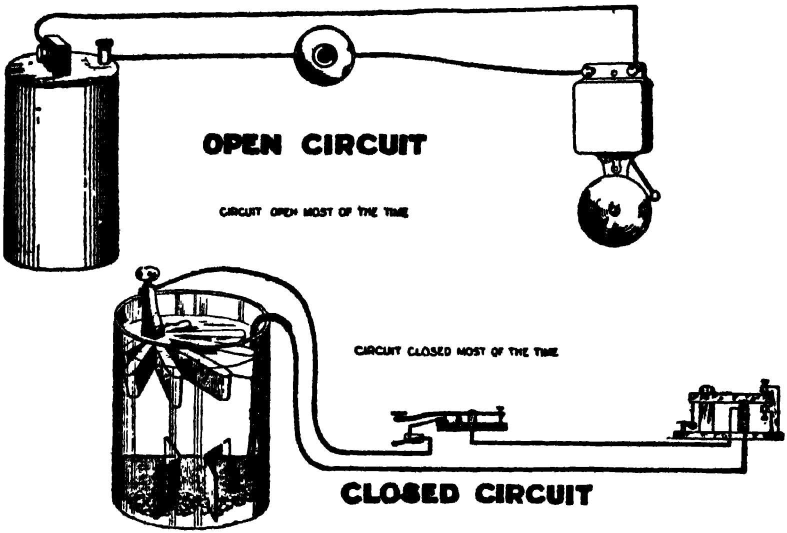
With respect to the second method, cells are classified as:

1. One fluid;
2. Two fluid.

Ques. Describe a primary cell.

Ans. A primary cell consists of a vessel containing a liquid in which two dissimilar metal plates are immersed.

In *one fluid* cells, both metal plates are immersed in the same solution. In *two fluid* cells, each metal plate is immersed in a separate solution, one

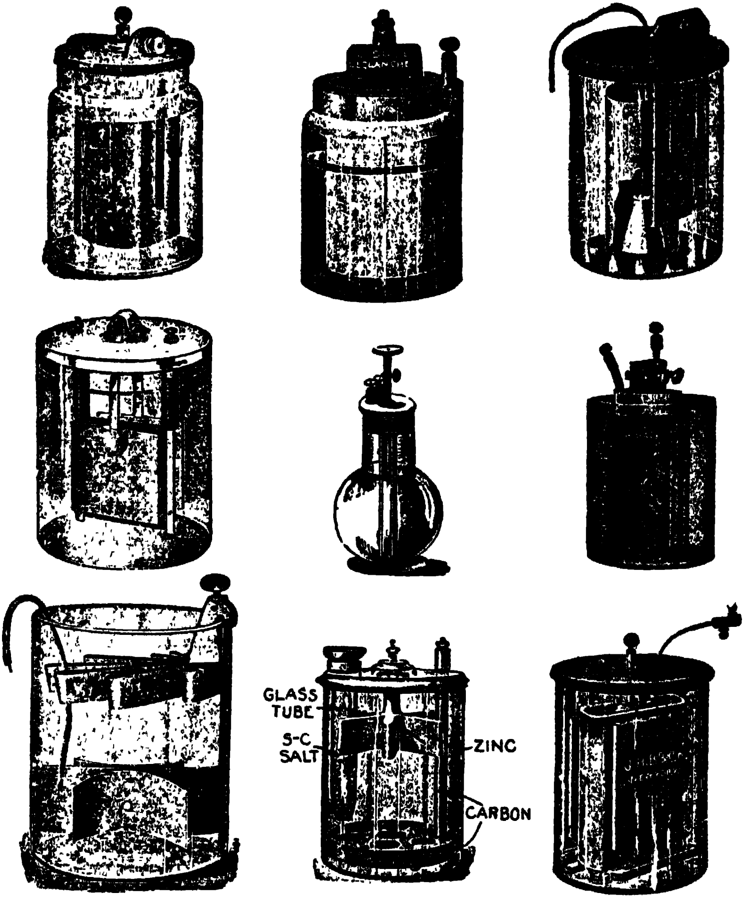


FIGS. 111 and 112.—Distinction between open and closed circuit showing familiar open, and closed circuit cells.

of which is contained in a porous cup which is immersed in the other liquid.

Ques What name is given to the metal plates?

Ans. They are called *elements*.



FIGS. 113 to 121.—Various primary cells. Fig. 113, carbon cell; fig. 114, Disque Leclanche cell (single fluid with solid depolarizer); fig. 115, Fuller telephone standard cell (adapted to long distance telephoning); fig. 116, Edison single fluid cell (caustic soda electrolyte; suitable for ignition and R. R. signal work); fig. 117, Grenet cell (suitable for experimental work); fig 118, Bunsen two fluid cell (suitable for experimental work); fig. 119, Daniell gravity "crow foot" pattern two fluid cell (*gravity* instead of a porous cup is depended upon to keep the liquids separate; suitable for closed circuit work); fig. 120, Partz acid gravity cell with depolarizer (the effective depolarizer permits both open and closed circuit work); fig. 121, Wheelock cell (carbon and zinc elements).

Ques. What is the fluid called?

Ans. The *electrolyte* or *exciting fluid.*

The term "electropoion" is a trade name for the electrolyte employed in the Fuller cell.

Action of a Primary Cell.—The fundamental fact on which

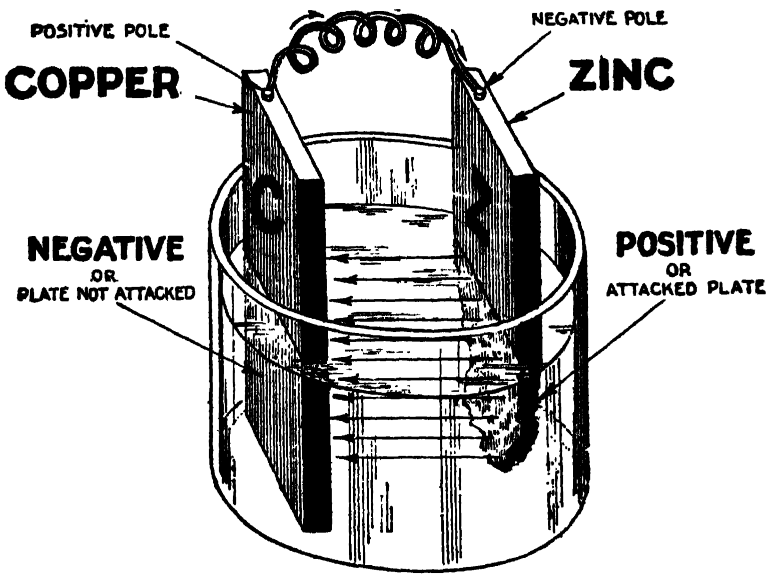
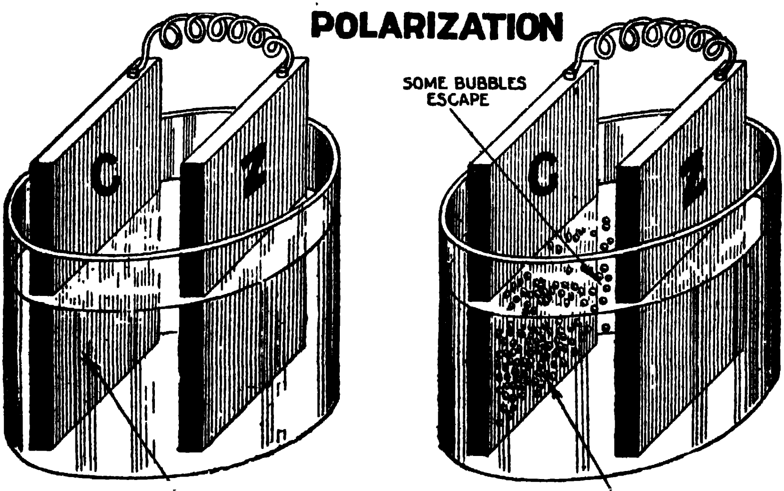


FIG. 122.—Elementary primary cell illustrating the action of a cell. ***An important point*** to be noted is that the polarity of each plate is different from that of its terminal. Thus, the zinc terminal is negative, but the zinc plate is positive; an inspection of the illustration will show that this is necessary for current flow.

the electro-chemical generation of current depends is, that *if a plate of metal be placed in a liquid there is a difference of* ***electrical condition*** *produced between them of such sort that the metal*

either takes a lower or higher electrical pressure than the liquid, according to the nature of the metal and the liquid.

If two different metals be placed in one electrolytic liquid, then there is a difference of state produced between them, so that, if joined by wire outside the liquid, a current of electricity will traverse the wire. This current proceeds in the liquid from the metal which is most acted upon chemically to that which is least acted upon.



FIGS. 123 and 124.—Elementary primary cell illustrating polarization, Fig. 123, shows entire surface of copper element exposed to action of electrolyte on first closing circuit; fig. 124, condition after circuit is left closed for some time, surface of the copper becomes covered with bubbles of hydrogen gas, which interferes with the production of current *and the cell is said to be polarized.*

Referring to fig. 122, the construction and action of a simple primary cell may be briefly described as follows:

Place in a glass jar some water having a little sulphuric or other acid added to it. Place in it separately two clean strips, one of zinc Z, and one of copper C. This cell is capable of supplying a continuous flow of electricity through a wire whose ends are brought into connection with the

two strips. When the current flows, the zinc strip is observed to waste away, its consumption in fact furnishing the energy required to drive the current through the cell and the connecting wire. The cell may therefore be regarded as a kind of chemical furnace in which the fuel is the zinc.

Ques. How are the positive and negative elements of a primary cell distinguished?

Ans. The plate attacked by the electrolyte is the positive element, and the one unattacked the negative element.

Chemical Changes, Polarization.—The chemical changes which take place in a simple cell, consisting of zinc and copper elements in an electrolyte of dilute sulphuric acid, may be briefly described as follows:

When the two elements are connected and the current commences to flow, the sulphuric acid acts on the surface of the zinc plate and forms sulphate of zinc. The formation of this new substance necessitates the liberation of some of the hydrogen contained in the sulphuric acid, and it will be found that bubbles of free hydrogen gas speedily appear on the surface of the negative element, that is, on the copper plate.

While the zinc is being dissolved to form zinc sulphate, hydrogen gas is liberated from the sulphuric acid.

Some bubbles of the gas rise to the surface of the electrolyte and so escape into the air, *but much of it clings to the surface of the copper element which thus gradually becomes covered with a thin film of hydrogen.*

Partly on account of the decreased area of copper plate in contact with the electrolyte, and partly because the hydrogen tends to produce a current in the opposite direction, the useful electrical output becomes considerably diminished and the cell is said to be *polarized*. This state of affairs may be rectified by stirring up the electrolyte, or by shaking the cell, so as to assist the hydrogen bubbles to detach themselves from the surface of the copper plate and make their way to the atmosphere through the electrolyte. This, however, is only a temporary remedy, as the polarized condition will soon be reached again, and a further agitation of the cell will be necessary. Hence, a simple cell of this kind is not desirable for practical work. and it must be modified to adapt it to constant use.

When the sulphuric acid in a cell acts in the zinc element and produces sulphate of zinc, a certain amount of work is done which is manifested partly in the form of useful electric energy, and partly as heat which warms the electrolyte and which is thereby lost for all practical purposes.

Ques. If the zinc and copper electrodes of a simple cell

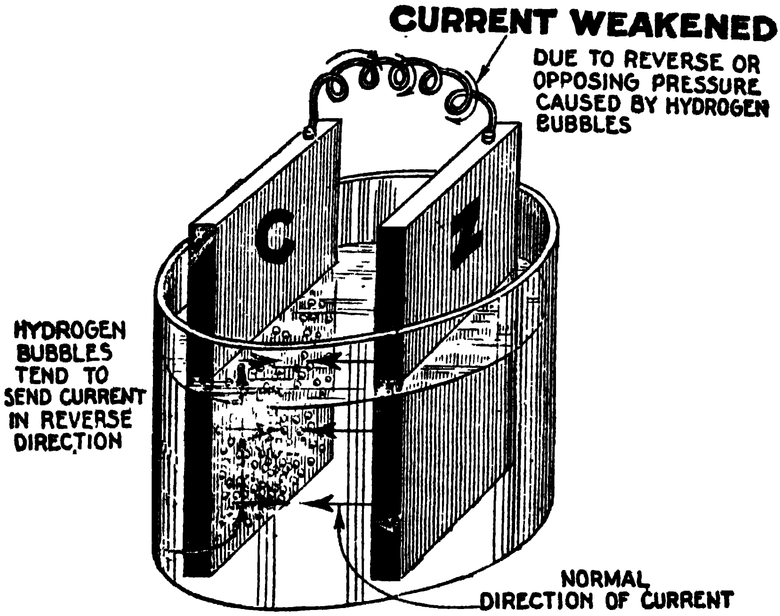


FIG. 125.—Elementary primary cells illustrating how the current is weakened by polarization due to the fact that the hydrogen bubbles tend to produce a current in the opposite direction.

be not connected externally what changes take place within the cell?

Ans. The zinc plate immediately becomes strongly charged with negative electricity, and the copper plate weakly so. As

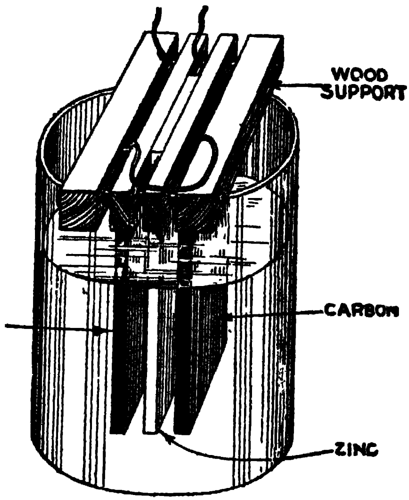


FIG. 126.—Home made primary cell. ***In construction,*** make a clamp of wood which has been soaked in paraffin, and fasten one end of the plates in it as shown, the zinc plate between the two carbons. The wood strips of the clamp are each 7 ins. long; the outer strips are 1 in. sq., the inner two are 1x⅜ in. Four bolts at the ends of the clamp hold it together. Before screwing together lay a piece of heavy copper wire under the clamp and across the top of the plate. The two carbon plates are connected together to one wire; the zinc is connected to the other wire. The plates are now hung in a glass jar 6×8 ins., the wood clamp resting across the top. The electrolyte is made by dissolving a lb. of sodium bichromate in a gal of water, and adding slowly a pound of strong sulphuric acid. This cell gives two volts and a large current. When it begins to show signs of exhaustion add a little more acid. Some arrangement should be made for drawing the plates out of the solution when not in use, and hanging them just above the jar.

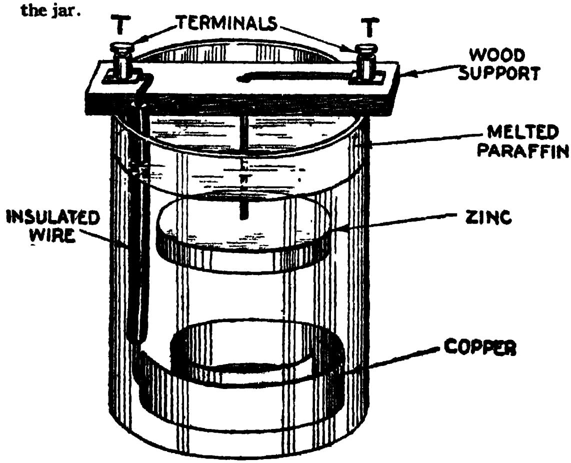
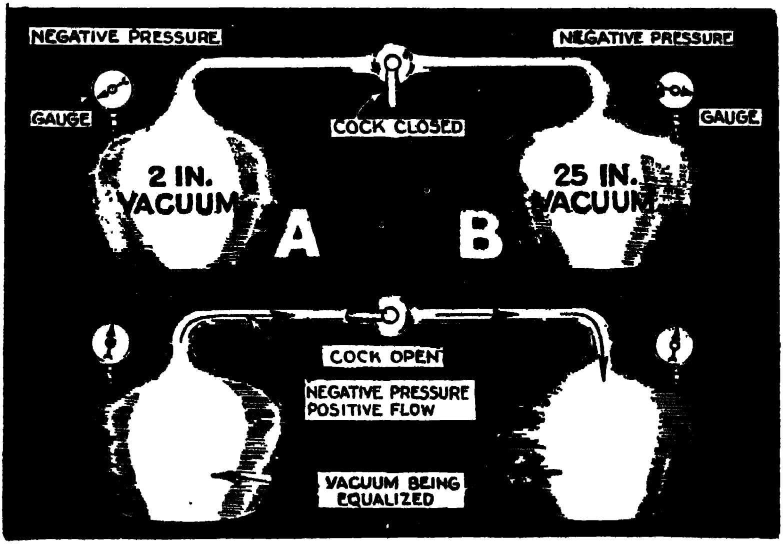


FIG. 127.—Home made gravity cell. Procure a glass jar 6 × 8 ins. high. Next take a piece of sheet copper ½x15 ins. long and to one end solder or rivet a piece of No. 16 or 18 rubber insulated copper wire about 15 ins. long; first removing the insulation from the ends of the wire and cleaning same. Coil up the strip of copper as shown. The free end of the wire forms a positive terminal of the cell. Procure zinc disc about ⅛ in. thick and 4 or 5 ins. in diameter. To its center rivet a piece of No. 16 or 18 copper wire; over the rivet melt a small piece of paraffine. Pass wire through the wooden support shown at the top of the jar and connected to the negative terminal. Dip jar in melted paraffine to prevent creeping of solution. The binding posts H and D, are the terminals. For the electrolyte take 3 lbs. of copper sulphate, mix with enough rain water to cover the zinc. Let cell stand 10 hrs. short circuited after which the cell must be kept on close circuit having about 50 ohms resistance.

long as the plates remain unconnected, and the zinc is pure, no further action takes place.

Ques. If the electrodes be connected externally what happens?

Ans. If the plates be connected by a wire outside the electrolyte, the tendency which dissimilar electrical charges have



FIGS. 128 and 129.—Pneumatic analogy illustrating how there can be a positive flow when both plates of a battery are negatively electrified as explained in the accompanying text.

to neutralize one another causes a flow of negative electricity through the wire from zinc to copper, and a positive flow in

NOTE.—*When a current* is produced by a *Daniell's cell*, copper is deposited on the copper plate, copper sulphate is used up, the sulphuric acid remains unchanged in quantity, zinc sulphate is formed, and zinc is used up. If however, the copper sulphate solution be too weak, the water is decomposed instead of the copper sulphate, and hydrogen is deposited on the copper plate. This deposition of hydrogen lowers the voltage, and care should, therefore be taken to keep up a sufficient supply of crystals of copper sulphate.

the opposite direction. The "static" charge being thus disposed of, a fresh charge is given to the plates by the action of the acid, which commences to dissolve the zinc. As long as the wire connects the copper and zinc plates, the acid will continue its action on the zinc until either acid or zinc is exhausted.

The reader may ask: how can there be a positive flow when both plates are negatively electrified?

An analogy is the best way to make this point clear: Imagine two equal vessels, from each of which the air has been partially exhausted, but from one A, a much greater quantity of the air has been taken than from the other B. Connect A and B, by a tube. Now, although both vessels have less than the atmospheric pressure, that is, both have "negative" pressures, yet a current of air will flow from B, to A, until the pressures in each are equalized; that is, until both have equal "negative charges" of air.

There is a second important effect of the acid solution or electrolyte in a cell. *If pure sulphuric acid were used, the first action or production of an electrical charge on the zinc plate would be the same, but when the plates were joined by the wire the current would soon cease.*

The reason for this lies in the fact that the sulphate of zinc, which is the compound produced by the acid plus the zinc, being insoluble in pure undiluted sulphuric acid, remains on the surface of the zinc plate. The coating of sulphate of zinc thus formed also operates as a protective agent, and no further electrical charge can be induced until it is removed. The addition of water to the acid has the effect of allowing the sulphate of zinc to dissolve, and the zinc plate is left free for further action.

Ques. What governs the rate of current flow of a primary cell?

Ans. The size of the elements and their proximity.

Effects of Polarization —The film of hydrogen bubbles affects the strength of the current of the cell in two ways:

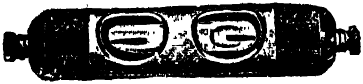


FIG. 130.—Polarity indicator. It indicates the negative and positive poles when connected in circuit.

FIG. 131.—Students demonstration battery. An excellent battery for studying the laws of the voltaic cell, such as internal resistance, effects of amalgamating the zinc, use of various solutions, etc. With a complete set of elements the various forms of batteries in common use are readily assembled.

BATTERY DIRECTIONS

Amalgamating.—A good method for amalgamating the zinc element is to dip it into acid, then pour a few drops of mercury on the surface and rub in with a piece of cloth attached to a stick. This is perhaps the best and quickest method although the most expensive.

Amalgamating Fluid.—Two-ounces mercury, 1 ounce aqua regia, 10 ounces water. Dip zinc into solution and then wash with water. No need of brush or rag.

Leclanche Cell.—Place 6 ounces ammonium chloride into jar and fill with water to two-thirds its capacity. Stir well until the salt is entirely dissolved. Place elements with zinc outside porous cup as illustrated.

Carbon Cylinder Cell.—Directions furnished under Leclanche cell apply to this type of cell except that zinc rod is placed inside carbon cylinder.

Samson Cell.—Directions furnished under carbon cylinder cell apply to this type of cell.

Grove Cell.—Outer cell contains amalgamated zinc plate dipping into dilute sulphuric acid (by weight 10 parts water to 1 part acid). In inner porous cup, a piece of platinum dips into nitric acid of full strength. Obnoxious nitrogen oxide fumes may be suppressed in a large measure by the addition of a small quantity of potassium dichromate.

Bunsen Cell.—This cell is merely a modification of the Grove cell, in which the expensive platinum is replaced by an electrode of gas carbon.

In both the Grove and Bunsen cells the nitric acid may be replaced by a chromic acid solution.

Grenet Cell.—In this cell the zinc plate between two carbon plates dips into a chromic acid solution (see below). When this cell is exhausted, the rich reddish color of chromic acid will be replaced by a muddy dark green color.

Chromic Acid Solution.—There are many different formulæ, but the most convenient method of making a generally useful acid is by simply dissolving prepared chromic acid salt in water. A useful formula is, 30 parts sodium dichromate, 100 parts water and 23 parts sulphuric acid (sp. gr. 1.845) all by weight.

Plunge Battery.—Elements and directions under Grenet type apply to this type of battery.

Daniell Battery.—The zinc element is placed in a porous cup containing sulphuric acid (1 part acid to 20 parts water, by weight). The copper element encircles a porous cup and dips into saturated solution copper sulphate, kept continually saturated by the addition of an excess of copper sulphate crystals on bottom of jar. Solution is more effective by addition of few cubic centimeters sulphuric acid.

1. It weakens the current by the increased *resistance* which it offers to the flow, for bubbles of gas are bad conductors;
2. It weakens the current by setting up an opposing *electromotive force*.

Hydrogen is almost as oxidizable a substance as zinc, especially when freshly deposited (in the "nascent" state), and is electropositive; hence,

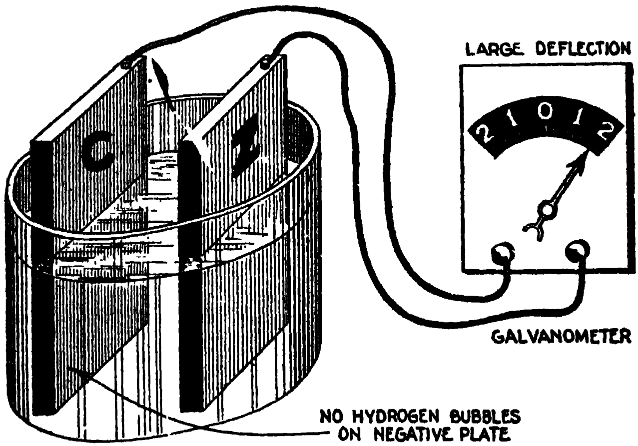


FIG. 132.—Condition of cell before polarization takes place. Note no hydrogen bubbles on negative plate, allowing full flow of current as indicated by large deflection of galvanometer.

the hydrogen itself produces a difference of pressure, which would tend to start a current in the opposite direction to the true zinc-to-copper current. It is therefore an important matter to abolish this polarization otherwise the currents furnished by batteries would not be constant.

Methods of Depolarizing.—One of the chief aims in the arrangement of the numerous cells which have been devised is to avoid polarization. The following are the methods usually employed.

1. Chemical methods;
   a. Oxidation of the hydrogen by potassium bichromate and by nitric-acid.
   b. Substitution of the hydrogen by some other substance which does not give a counter electromotive force of polarization; for instance, in the Daniell cell by replacement of the copper in copper sulphate by the hydrogen, the copper being deposited on the positive pole.

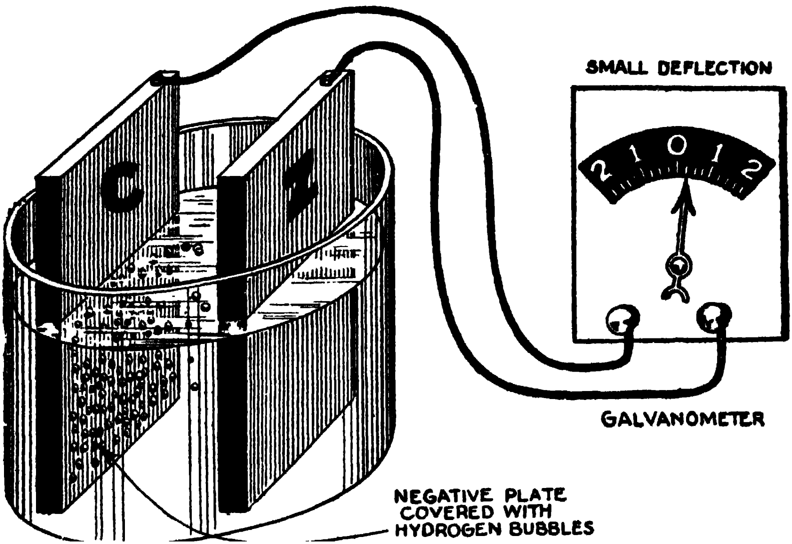


FIG. 133.—Polarized cell. Note that the negative plate is covered with hydrogen bubbles, rendering most of its surface inactive. When in this condition very little current will flow as indicated by the small deflection of the galvanometer.

2. Electro-chemical means;

It is possible by employing double cells, to secure such action that some solid metal, such as copper, shall be liberated instead of hydrogen bubbles, at the point where the current leaves the liquid. This electro-chemical exchange obviates polarization.

3. Mechanical methods.

a. Agitation of the liquid or of the positive electrode, in order to prevent the accumulation of hydrogen thereon.

b. Corrugating or roughing the positive electrode, as in the Smee cell. This causes the hydrogen gas to form in large bubbles which rise to the surface more rapidly than the small bubbles which form on a smooth electrode.

In the simplest form of cell, as zinc, copper, and dilute sulphuric acid, no attempt has been made to prevent the evil of polarization, hence, it

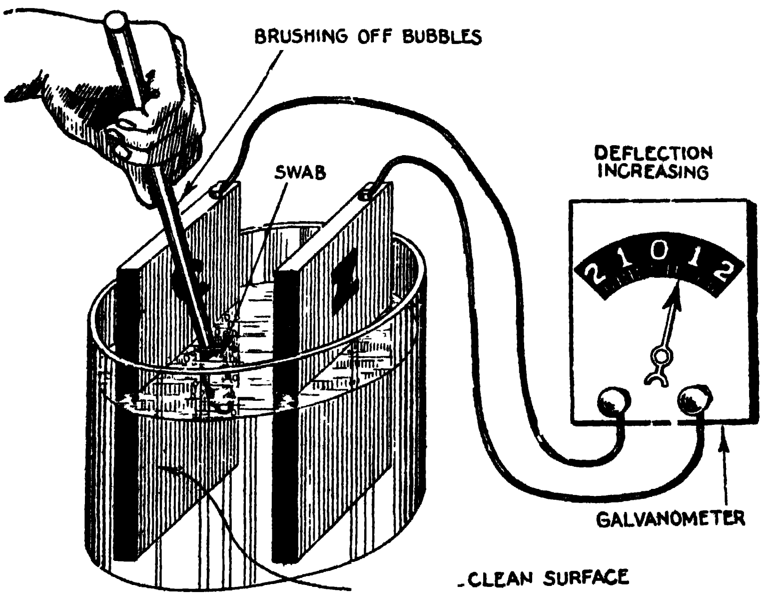


FIG. 134.—*Depolarizing* a cell *mechanically*. If the hydrogen bubbles adhering to the negative plate be brushed off with a swab as shown, the deflection of the needle will increase thus indicating a stronger circuit.

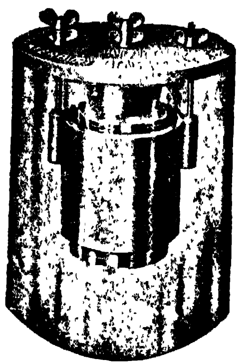
will quickly polarize when the current is closed for any length of time, and may be classified as an open circuit cell.

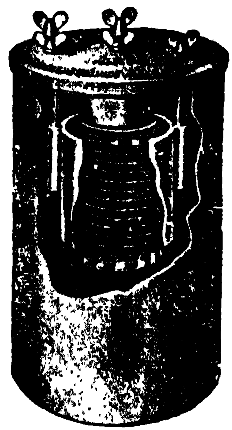
NOTE.—*When polarization* is remedied by chemical means, the chemical added is one that has a strong affinity for hydrogen and will combine with it, thus preventing the covering of the negative plate with the hydrogen gas

Ques. What is a depolarizer?

Ans. A substance employed in some types of cell to combine with the hydrogen which would otherwise be set free at the positive electrode and cause polarization.

The chemical used for this purpose may be either in a *solid* or *liquid* form, which gives rise to several types of cell, such as cells with a single fluid, containing both the acid and the depolarizer, cells with a single exciting fluid and a solid depolarizer, and cells with two separate fluids



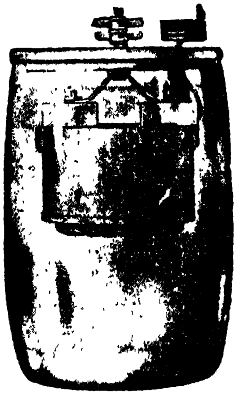


FIGS. 135 and 136.—Waterbury primary cells. Fig. 135, glass jar type; fig. 136, porcelain jar type.

In the two fluid cell, the zinc is immersed in the liquid (frequently dilute sulphuric acid) to be decomposed by the action upon it, and the negative plate is surrounded by the liquid depolarizer, which will be decomposed by the hydrogen gas it arrests, thereby preventing polarization.

In *open circuit cells* polarization does not have much opportunity to occur, since the circuit is closed for such a short period of time; hence, these cells are always ready to deliver a strong current when used intermittently.

In *closed circuit cells* polarization is prevented by chemical



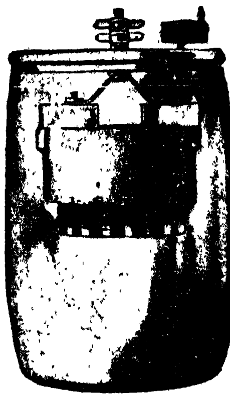
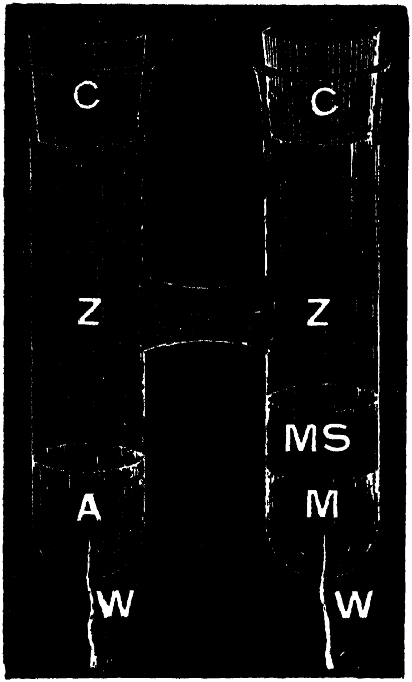


FIG. 137.—Waterbury ARA cell; indication of exhaustion 1: The first indication of approaching exhaustion occurs at about 375 ampere hours when, under ordinary conditions of discharge small holes appear above the reinforcing rib and gradually encircle the zinc.

FIG. 138.—Waterbury ARA cell; indication of exhaustion 2: From the point described in fig. 137, the zinc is gradually consumed at the bottom, until the lower rib has been eaten away, which will be at about 475 ampere hours.

FIG. 139.—Waterbury ARA cell; indication of exhaustion 3: The zinc is now consumed from the bottom upward until about 2 inches only of the zinc remains when the rated capacity, 500 ampere hours, has been used, but there is still considerable capacity remaining, the amount depending upon the nature of the work and general service conditions.

FIG. 140.—Waterbury ARA cell; indication of exhaustion 4: After the small holes appear as in fig. 139, there will be approximately one-quarter (¼) of the rated life of the cell still available for use. After a substantial part of the zinc has disappeared as shown in fig. 139, the cell must be watched carefully to procure maximum life without failure, taking into consideration the class of service for which the battery is being used.



action, so that the current will be constant and steady till the energy of the chemicals is expended.

Ques. What is a depolarizer bag?

Ans. A cylinder of hemp or other fabric used in place of a porous pot in some forms of Leclanche cell, and also as a support for the depolarizing mass in some forms of dry cell where the electrolyte is of a thin gelatinous nature.

Volta's Contact Law.—*When metals differing from each other are brought into contact, different results are obtained, both as to the kind of electrification as well as the difference of pressure.*

FIG. 141.—Clark's standard test cell. Latimer Clark's standard cell assumes a variety of forms. The H-form is arranged as shown. The vessel to the left contains, at A, an amalgam of pure zinc. The other vessel contains, at M, mercury covered with pure mercurous sulphate, Hg_2SO_4. Both vessels are then filled, above the level of the cross tube, with a saturated solution of zinc sulphate Z,Z, to which a few crystals of the same are added. Tightly fitting corks C,C, prevent loss by evaporation. The voltage of this cell in legal volts is 1.438. (1 −.00077(t −15 deg. C.)—(*Ayrton*).

Volta found that iron, when in contact with zinc, becomes negatively electrified; the same takes place, but somewhat weaker, when iron is touched with lead or tin. When, however, iron is touched by copper or silver, it becomes positively electrified. Volta, Seebeck, Pfaff, and others

have investigated the behavior of many metals and alloys when in contact with each other.

The following lists are so arranged that those metals first in each list become positively electrified when touched by any taking rank after them:

CONTACT SERIES OF METAL

According to Volta	*According to Pfaff*	
+zinc	+zinc	copper
lead	cadmium	silver
tin	tin	gold
iron	lead	uranium
copper	tungsten	tellurium
silver	iron	platinum
gold	bismuth	−palladium
graphite	antimony	
−manganese ore		

Volta laid down a law regarding the position of the metals in this table which may be stated as follows:

Volta's Law.—*The difference of pressure between any two metals is equal to the sum of the differences of pressures of all the intermediate members of the series.*

Hence, it is immaterial for the total effect whether the first and the last are brought into contact directly, or whether the contact is brought about by means of all or any of the intermediate metals.

Volta's law further asserts that when any number of metals are brought into contact with each other, but so that the chain closes with the metal with which it was begun, the total difference must be zero.

by the action upon it, while the negative plate is placed in the liquid depolarizer which is decomposed by the hydrogen arrested by it, thus preventing polarization.

In some forms of cell, the two liquids are separated by a porous partition of unglazed earthenware, which, while it prevents the liquids mixing except very slowly, does not prevent the passage of hydrogen and electricity.

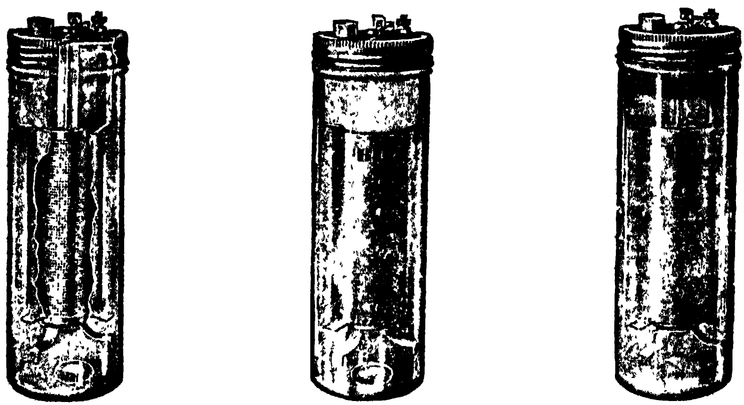


FIG. 146.—Waterbury telecell zinc cylinder cut away to expose the interior construction of the cell to inspection. The perforated cylindrical basket inside of the zinc cylinder contains the depolarizing element, that is, copper oxide. The small legs and feet at the bottom keep elements centralized. The copper oxide is sealed in the basket to prevent sifting out during shipment.

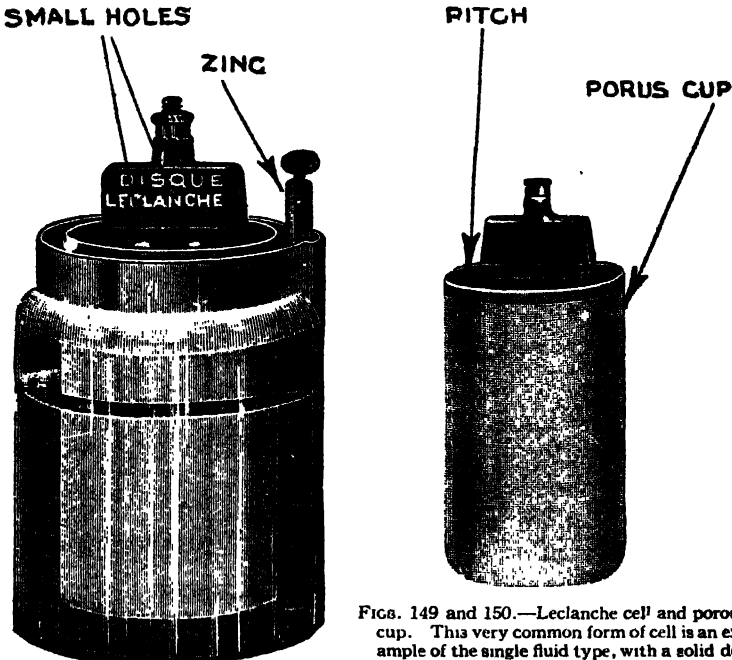
FIG. 147.—Waterbury telecell as shipped. Cakes of caustic soda at the top, just above the zinc cylinder. The capsule of battery oil is shown at the bottom of the jar. When water is added the soda is dissolved, the capsule melted, and the perforations in the copper oxide basket opened.

FIG. 148.—Waterbury telecell after water has been added, the electrolyte made and the cell in working condition. ***In operation,*** as current is drawn from the cell, the little bars forming the window at the top of the zinc cylinder, gradually dissolve and near the end of the life of the cell they disappear. This feature gives advance notice that the cells are nearly exhausted and failure in service may be prevented.

Complete depolarization is usually obtained also in single fluid cells, having in addition a depolarizing solid body, such as oxide of manganese, oxide of copper, or peroxide of lead, in contact with the carbon pole. Such cells really do not belong to the single fluid cells, and are considered in the two fluid class.

A few examples of single and double fluid primary cells will now be described.

The Leclanche Cell.—This cell was invented by Leclanche, French electrician, and was the first cell in which sal-ammoniac was used. This form of cell, as shown in fig. 149, is in general use for electric bells, its great recommendation being that, once



FIGS. 149 and 150.—Leclanche cell and porous cup. This very common form of cell is an example of the single fluid type, with a solid depolarizer surrounding the negative element; the latter is generally carbon, the positive element being zinc. The liquid used is a strong solution of ammonium chloride, commonly known as sal-ammoniac, and which resembles table salt. In the porous cup type of cell, a carbon slab is placed in the porous cup, and is surrounded by a mixture of small pieces of carbon and manganese dioxide, the top being covered by means of pitch, leaving one or two small holes for air and gas to pass through. The depolarizer will take care of a limited amount of the hydrogen produced when the cell is on closed circuit, but if the circuit be closed for any length of time polarization occurs. The cell is thus of the open circuit class, and will furnish a good current where it is required only intermittently. Zinc is dissolved only when the cell is being used. This type of cell, or its modification, is used for gas lighting and bell work. The cell requires very little attention. Water must be added as the solution evaporates, and the zinc rod replenished when necessary. The pressure of the cell is about 1.48 volts and the internal resistance about 4 ohms

charged, it retains its power without attention for a considerable time.

Two jars are employed in its construction; the outer one is of glass, contains a zinc rod, and is charged with a solution of ammonium chloride, called sal-ammoniac.

The inner jar is of porous earthenware, containing a carbon plate, and is filled with a mixture of manganese peroxide and broken gas carbon.

When the carbon plate and the zinc rod are connected, a steady current of electricity is set up, the chemical action which takes place being as follows: *the zinc becomes oxidized by the oxygen from the manganese peroxide, and is subsequently converted into zinc chloride by the action of the sal-ammoniac.*

After the battery has been in continuous use for some hours, the manganese becomes exhausted of oxygen, and the force of the electrical current is greatly diminished; but if the battery be allowed to rest for a short time, the manganese obtains a fresh supply of oxygen from the atmosphere, and is again fit for use.

After about 18 months' work, the glass cell will probably require recharging with sal-ammoniac, and the zinc rod may also need renewing; but should the porous cell get out of order, it is better to get a new one than to attempt to recharge it.

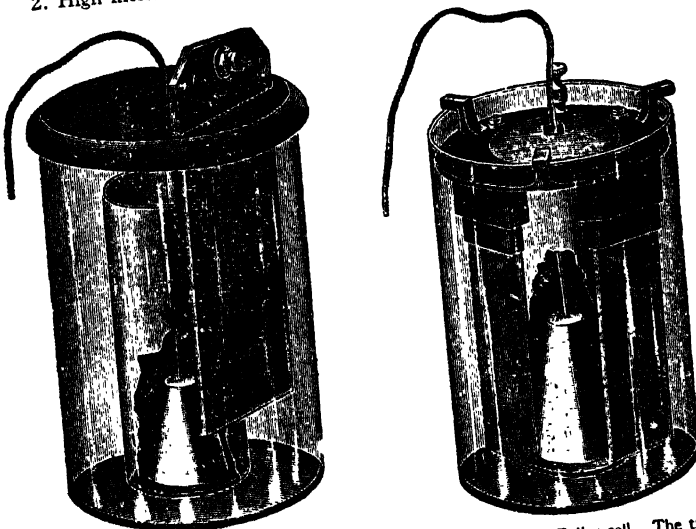
The directions for setting up a Leclanche cell are as follows:

1. Place in the glass jar six ounces of sal-ammoniac, and pour in water until the jar is one-third full, then stir thoroughly.
2. Place the porous cup in the solution, and if necessary add water until it rises to within 1½ inches of the top of the porous cup.
3. Put the zinc rod in place and set the cell away (not connected up), for about 12 hours, so as to allow the liquid to thoroughly soak into the porous cup. This will lower the level of the liquid to about one-third the height of the jar. The cell will then be ready for use. As the level of the liquid is lowered by evaporation, it should be maintained at the stated height by adding water.

The Leclanche cell is adapted to open circuit work, being extensively used for ringing electric bells.

The objections to the Leclanche cell are:

1. Rapid polarization;
2. High internal resistance due to porous pot;



FIGS. 151 and 152.—The telephone standard and compound forms of Fuller cell. The type shown in fig. 151, is especially adapted to long distance telephoning, and that shown in fig. 152, to incandescent lamps, motors, nickel and other electroplating. The Fuller cell is of the double fluid variety and has the advantage over the Grenet type, in that the zinc is always kept well amalgamated and does not require removal from the solution. The Fuller cell is suitable for open and semi-closed circuit work; its electromotive force is about 2.14 volts.

3. Restricted space for electrolyte causing rapid lowering of level of liquid by evaporation;
4. Eating away of the zinc rod at the surface of the liquid rendering the rod useless before the lower part is consumed.

Fuller Bichromate Cell.—In the bichromate cells or the

chromic acid cells, bichromate of soda, or bichromate of potassium, is used for the depolarizer, water and sulphuric acid being added for attacking the zinc.

The Fuller cell is of the two fluid type. *A pyramidal block of zinc at the end of a metallic rod covered with guttapercha is placed in the bottom of a porous cup containing an ounce of mercury. The cup is then filled with a very dilute solution of sulphuric acid or water and placed in a jar of glass or earthenware containing the bichromate solution and the carbon plate.*

The diffusion of the acid through the porous cup is sufficiently rapid to attack the zinc, which being well amalgamated, prevents local action; while the hydrogen passes through the porous cup and combines with the oxygen in the bichromate of potassium.

This type of cell has a pressure of 2.14 volts, and is suited to open circuit, or semi-closed circuit work. The directions for setting up a Fuller cell are as follows:

1. To make the "electropoion" fluid, mix together one gallon of sulphuric acid and three gallons of water, and in a separate vessel, dissolve six pounds of bichromate of potash in two gallons of boiling water; then thoroughly mix together the two solutions.
2. Immerse the zinc in a solution of dilute sulphuric acid, and then in a bath of mercury, and rub it with a brush or cloth so as to reach all parts of the surface.
3. Pour into the porous cell one ounce (a tablespoonful) of mercury, and fill the porous cell with water up to within two inches of the top.
4. Place the porous cell and the carbon plate in the glass jar, as in figs. 151 and 152, and fill glass jar to within about three inches of the top with a mixture of three parts of electropoion fluid to two parts of water.
5. The zinc should be lifted out occasionally and the sulphate washed off.
6. The supply of mercury in the porous cell should be maintained, so as to have the zinc always well amalgamated.
7. To renew, clean all deposits from carbon plate and zinc, and set up with fresh solution.

The Edison Cell.—This is a single fluid cell with a solid depolarizer, as shown in figs. 153 and 177 and is well adapted for use on closed circuits.

The positive element is zinc, and the negative element, black oxide of copper. The exciting fluid is a solution of caustic potash. The black oxide of copper plates are suspended from the cover of the

FIG. 153.—Edison caustic soda cell with rectangular shape jar and single plate element. The Edison cell is suitable for large stationary gas engine ignition, railroad crossing signals, electroplating, fire alarms, telephone circuits, etc.

jar by a light framework of copper, one end of which forms the positive pole of the battery. A zinc plate is suspended on each side of the copper oxide element and kept from coming in contact with the latter by means of vulcanite buttons.

When the cell is in action, the water is decomposed, and the oxygen thus liberated combines with the zinc and forms oxide

of zinc, which combines with the potash to form a double salt of zinc and potash. The last combination dissolves as rapidly as it is formed.

The hydrogen liberated by the decomposition of the water reduces the copper oxide to pure metallic copper. It is highly important that the copper oxide plates be completely submerged in the solution of caustic potash, and that heavy paraffin oil be poured on top of the solution to the depth

FIG. 154.—Bunsen cell. This is a two fluid cell and has a bar of carbon immersed in strong nitric acid contained in a porous cup This cup is then placed in another vessel, containing dilute sulphuric acid, and immersed in the same liquid is a hollow cylindrical plate of zinc, which nearly surrounds the porous cup. The hydrogen starting at the zinc, traverses by composition and recomposition, the sulphuric acid; it then passes through the porous partition, and enters into chemical action with the nitric acid, so that none of it reaches the carbon. Water is produced by this action, which in time dilutes the acid, and orange colored poisonous fumes of nitric oxide rise from the battery. If the nitric acid first be saturated with nitrate of ammonia, the acid will last longer and the fumes be prevented. Strong sulphuric acid cannot be used in any battery; one part of sulphuric acid is generally added to 12 parts by weight, or 20 by volume, of water. *Grove* used a strip of *platinum instead of carbon* in his cell. A solution of bichromate of potassium is frequently substituted for the nitric acid in the porous cup, thereby avoiding disagreeable fumes. Bunsen's and Grove's cells produce powerful and constant currents, and are well adapted for experiments, but they require frequent attention, and are expensive, so that they are little used for work of long duration. The electromotive force of these cells is about 1.8 volts.

of about ¼ of an inch to exclude the air. If oil be not used, the formation of creeping salts will reduce the life of the battery fully two-thirds.

The battery has a low voltage, about .7 of a volt, but as the internal resistance is also very low, quite a large current can be drawn from the cell.

The Bunsen Cell.—As shown in fig. 154, this is a two fluid cell

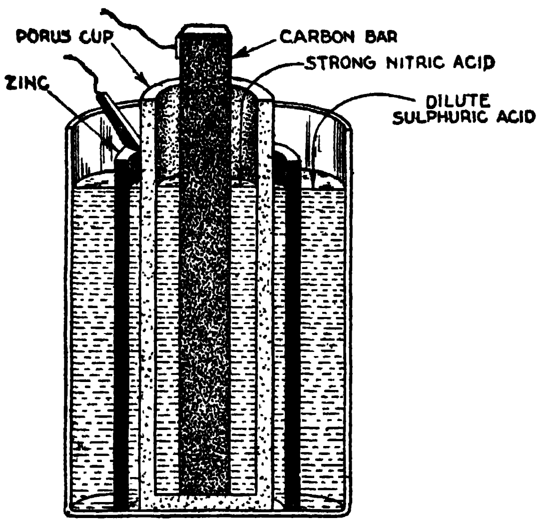


FIG. 155.—Sectional view of Bunsen cell showing elements, porous cup, electrolyte and anti-polarizer.

constructed with zinc and carbon electrodes. *The negative plate is carbon, the positive plate amalgamated zinc. The excitant is a dilute solution of sulphuric acid. The top part of the carbon is sometimes impregnated with paraffin (to keep the acid from creeping up).*

The voltage of the Bunsen cell increases after setting up for about an hour, and the full effect is not attained until the acid soaks through the

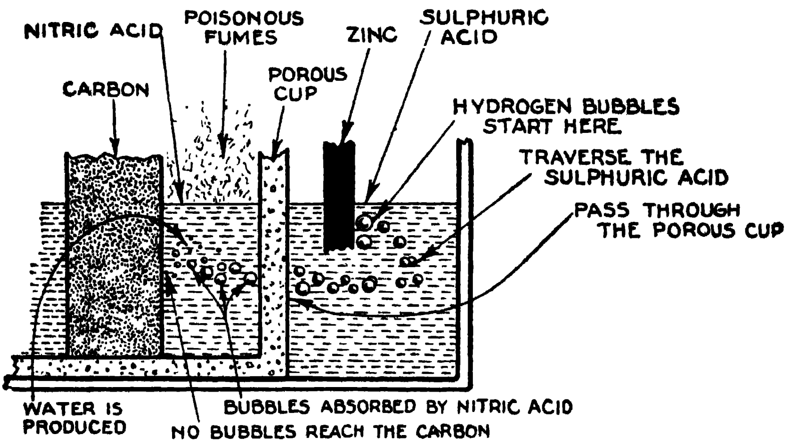


FIG. 156.—Detail of Bunsen cell showing how the anti-polarizer arrangement works. See description fig. 155.

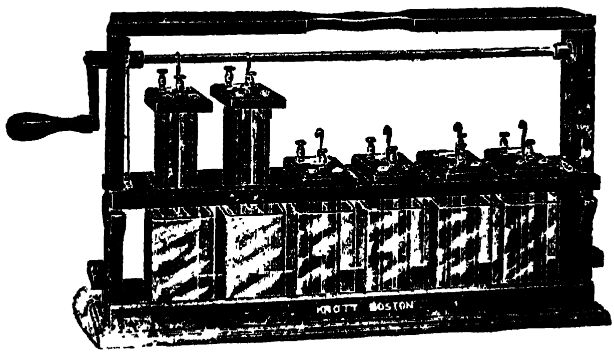
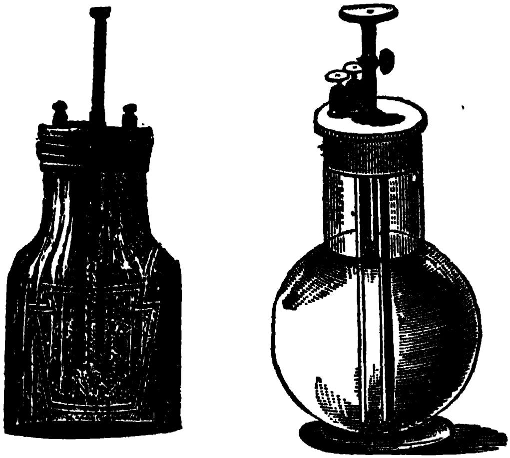


FIG. 157.—Knott high 6 cell school plunge battery. Each cell is a unit in itself and will deliver about two volts and a powerful current for a short time. The mounting is designed so that one or more cells, connected in series or parallel, may be used as desired. The illustration shows four cells in use, the two not in use suspended to the cross rod. By turning the crank all of the cells can be raised at one time.

porous cell. Carbons are not affected and last any length of time. The zinc is slowly consumed through the mercury coating.

Grenet Bichromate Cell.—In this cell, as shown in figs. 158 and 159, *the positive element is zinc and the negative element carbon. The electrolyte is a solution of bichromate of potash in a mixture of sulphuric acid and water.*



FIGS. 158 and 159.—American and French forms of Grenet cell. The elements are zinc and carbon. In the Grenet cell, a zinc plate is suspended by a rod between two carbon plates, so that it does not touch them, and when the cell is not in use the zinc is withdrawn from the solution by raising and fastening the rod by means of a set screw, as the acid attacks the zinc when the cell is on open circuit. This cell has an electromotive force of over 2 volts at first, and gives a strong current for a short time, but the liquid soon becomes exhausted, as will be noted by the change in the color of the solution from an orange to a dark red, and must be replenished. The zinc should be kept well amalgamated and out of the solution except when in use. It is a good type of cell for experimental work. To make the electrolyte take 3 ounces of finely powdered bichromate of potash and 1 pint of boiling water; stir with a glass rod and after it is cool, add slowly, stirring all the time, 3 ounces of sulphuric acid. The electrolyte may also be prepared as follows: take 4 ounces of bichromate of soda, 1¼ pints of boiling water, and 3 ounces of sulphuric acid.

The cell consists of a glass bottle containing the electrolyte and fitted with a lid from which the elements are supported. There is a zinc plate in the center and a carbon plate on each side.

The two carbon plates are connected to the same terminal, thus forming

a large positive surface, and the zinc plate to a terminal on the top of the brass rod to which it is attached. This rod slides through a hole in the lid so that the zinc plate can be lifted out of the electrolyte when the cell is not at work, thus preventing wasteful consumption of zinc and of the electrolyte. Bichromate cells give a strong current, the pressure of a single cell being 2 volts.

Daniell Cell.—This is one of the best known and most widely

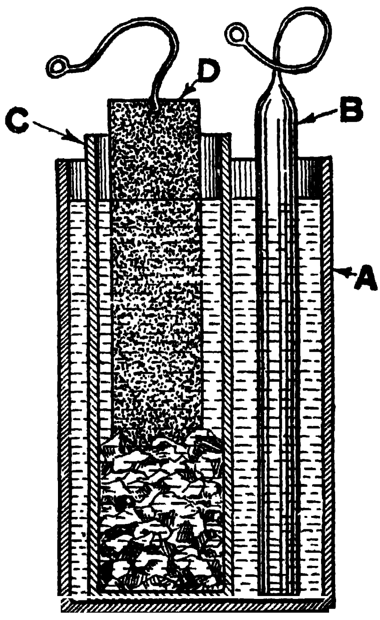


FIG. 160.—Simple Daniell cell for closed circuit work. To maintain a constant current for an indefinite time, it is only necessary to maintain the supply of copper crystals and zinc. The cell as shown in the figure is easily made by following the direction given in the accompanying text.

used forms of primary cell. It is a double fluid cell, *composed of an inner porous vessel containing an electrolyte of either dilute sulphuric acid or dilute zinc sulphate solution, and an outer vessel containing a saturated solution of copper sulphate.*

A zinc rod is placed in the inner electrolyte, and a thin plate of sheet copper in the outer electrolyte.

Sometimes this arrangement of the elements is modified, the outer vessel being made of copper and serving as the copper plate. This would then contain the copper sulphate solution, while the zinc sulphate and the zinc rod would be contained in the porous pot as before.

The chemical reactions which take place in a Daniell cell are as follows:

The zinc dissolves in the dilute acid, thus producing zinc sulphate, and liberating hydrogen gas. The free hydrogen passes through the walls of the porous pot, but when it reaches the copper sulphate solution it displaces some of the copper therefrom, and combines with this solution, forming sulphuric acid. The copper, which is thus set free, is deposited on the surface of the copper plate. In this way polarization is avoided, and a practically constant current is obtained.

When the zinc sulphate solution is employed in place of dilute acid, a similar series of chemical reactions occur, except that the zinc is liberated instead of hydrogen.

Daniell cells are used especially for electroplating, electrotyping and telegraphic work. The pressure of a single cell is about 1.08 volt.

Directions for Making a Daniell Cell.—The simple Daniell cell shown in fig. 160 may be easily made as follows:

The outer vessel A, consists of a glass jar (an ordinary glass jam jar will do) containing a solution of sulphuric acid (1 part in 12 to 20 parts of water), and a zinc rod B.

Inside the jar is placed a porous pot C, containing a strip of thin sheet copper D, and a saturated solution of sulphate of copper (also called "blue stone" and "blue vitrol").

The zinc is preferably of the Leclanche form, which will be found to be cleaner, more durable, and cheaper than a zinc sheet. The porous pot should be dipped in melted paraffin wax, both top and bottom, to

prevent the solution mingling too freely and "creeping." A few crystals of copper sulphate are placed in the pot as shown.

In mixing the sulphuric acid and water, ***the acid should be added to the water—never the reverse.*** Zinc sulphate is sometimes used instead, as it reduces the wasteful consumption of the zinc, but it should be pure.

FIG 161.—Daniell gravity cell, "crow foot" pattern. This is a two fluid cell in which gravity instead of a porous cup is depended upon to keep the liquids separate. The two solutions consist of copper sulphate and dilute sulphuric acid, the elements being made of zinc and copper.

With care the cell will last for weeks. When it weakens or "runs down," an addition of sulphuric acid to the outer jar and a few more crystals placed in the porous pot will put the cell in good condition.

Gravity Cells.—In a two liquid cell, instead of employing a porous cell to keep the two liquids separate, it is possible, where

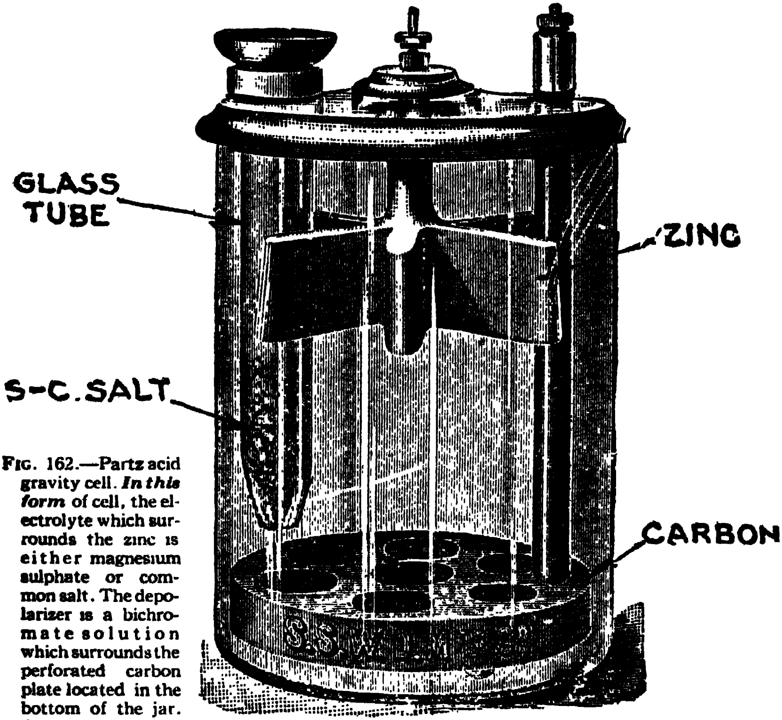
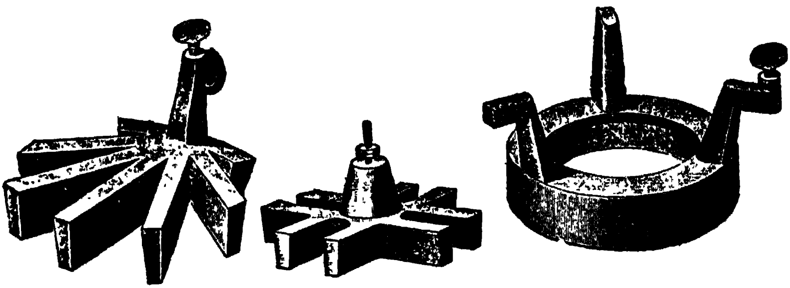
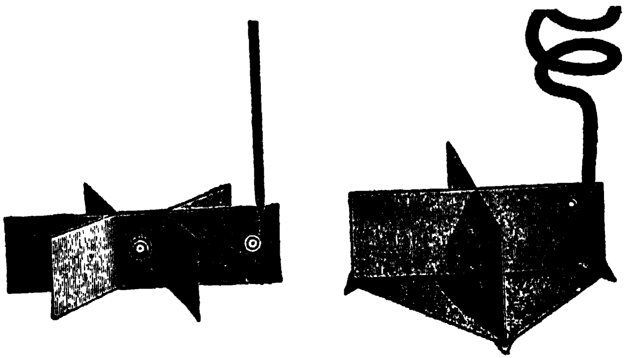


FIG. 162.—Partz acid gravity cell. *In this form* of cell, the electrolyte which surrounds the zinc is either magnesium sulphate or common salt. The depolarizer is a bichromate solution which surrounds the perforated carbon plate located in the bottom of the jar. A vertical carbon rod fits snugly into the tapered hole in the carbon plate, and extends through the cover forming the positive pole. The depolarizer, being heavier than the electrolyte, remains at the bottom of the jar, and the two liquids are thus kept separate. This depolarizer is placed on the market in the form of crystals, known as sulpho-chromic salt, made by the action of sulphuric acid upon chromic acid. When dissolved, its action is similar to that of the chromic acid solution. After the cell has been set up with everything else in place, the crystals are introduced into the solution, near the bottom of the jar, through the vertical glass tube shown, and slowly dissolve and diffuse over the surface of the carbon plate. When the cell current weakens a few tablespoonfuls of the salt introduced through the tube will restore the current to its normal value. The cell should remain undisturbed to prevent the solution mixing. Its voltage is from 1.9 to 2 volts, and the 6 in. × 8 in size has an internal resistance of about .5 ohm. Since the depolarizer is quite effective, the cell may be used on open or closed circuit work.

one of the liquids is heavier than the other, to arrange that the heavier liquid shall form a stratum at the bottom of the cell, the lighter floating upon it. Such arrangements are called *gravity cells;* but the separation is never perfect, the heavy liquid slowly diffusing upwards.



FIGS. 163 to 165.—Various zincs; fig. 163 crow foot; fig. 164 Lockwood; fig. 165 fire alarm.



FIGS. 166 and 167.—Two forms of copper element: fig. 166, regular form for crowfoot cell; fig. 167, signal pan bottom copper.

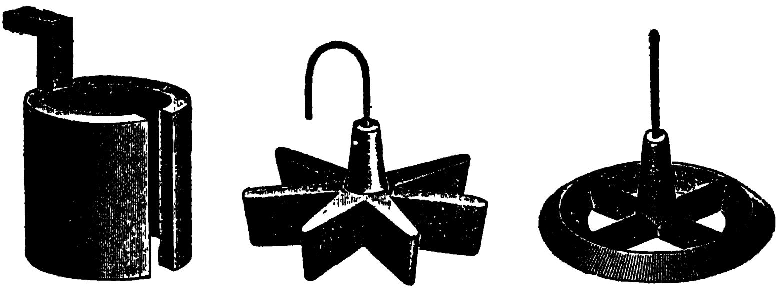
Daniell Gravity Cell.—In this cell, shown in fig. 161, the same elements are used as in the ordinary Daniell cell, but the porous pot is dispensed with, the two solutions being separated by the action of gravity as explained in the preceding paragraph.

The copper sulphate solution, being the heavier of the two, rests at the bottom of the battery jar, while the dilute sulphuric acid remains at the top. To suit this arrangement the copper and zinc elements are located as shown, the copper elements being at the bottom, and the zinc element, shaped like a ***crow's foot*** *(hence the name "****crow foot*** *cell") is suspended at the top.*

The absence of the porous pot decreases the internal resistance, but the voltage is the same as in the ordinary type of Daniell cell.

When a current is produced by a Daniell cell:

1. Copper is deposited on the copper plate;
2. Copper sulphate is consumed;
3. The sulphuric acid remains unchanged in quantity;



Figs. 168 to 170.—Various carbons; fig. 168 Cylindrical form; fig. 169 Calland star; fig. 170, wheel.

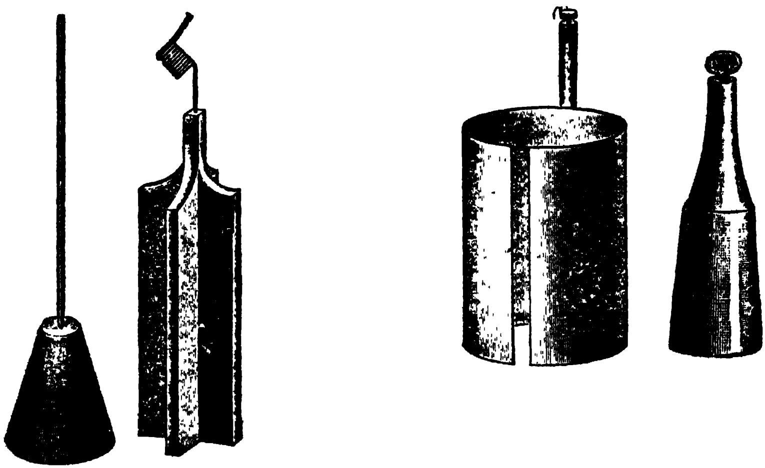
4. Zinc sulphate is formed;
5. Zinc is consumed.

If, however, the copper sulphate solution be too weak, the water is decomposed instead of the copper sulphate, and hydrogen is deposited on the copper plate. This deposit of hydrogen lowers the voltage, hence care should be taken to maintain an adequate supply of copper sulphate.

The voltage of a Daniell cell varies from about 1.07 volt to 1.14 volt, according to the density of the copper sulphate solution and the amount of zinc sulphate present in the dilute sulphuric acid.

Points Relating to the Care of Cells.—To get the best results from primary cells, they should receive proper attention and be maintained in good condition. The instructions here given should be carefully followed.

Cleanliness.—In the care of batteries, *cleanliness is essential in order to secure best results.* Zincs and coppers should be



Figs. 171 to 176.—Various zincs; fig. 171 Fuller; fig. 172 Daniell; fig. 173 Leclanche square; fig. 174 Leclanche round; fig. 175 Sampson; fig. 176 bottle.

thoroughly cleaned every time a cell is taken out of use. The zinc, after being thoroughly cleaned, should be rubbed with a little mercury. This prevents local action.

Porous cups should be soaked in clean water four or five hours and then wiped dry.

The terminals of each cell should be thoroughly cleansed and scraped bright so as to get good contact of the connecting wires and thus avoid extra resistance in the circuit.

Separating the Elements.—Obviously the positive and negative elements of a cell must not be in contact within the exciting fluid; they should be separated by a space of ⅜ to ½ inch. In the case of cells without porous cups, periodic attention must be given to ensure this condition being maintained.

Creeping.—As evaporation of the electrolyte takes place in a cell, it increases in strength, and crystals are left on the sides of the jar previously wetted by the solution, the action being very marked when the solution is a saturated one. *The space between these crystals and the side of the jar acts as a number of capillary tubes, and draws up more liquid, which itself evaporates and deposits crystals above the former ones.* Thus finally the film of crystals passes over the edge of the jar and forms on the outside, making a kind of syphon which draws off the liquid.

This action may, to a great extent, be prevented by warming the edges of the glass, or stoneware jars, and of the porous pots, before the cells are made up, and dipping them while warm into some paraffin wax melted in warm oil, a precaution that should always be carried out when a dense solution of zinc sulphate is employed in the cell.

Amalgamated Zinc.—To "amalgamate" a piece of zinc, *dip it into dilute sulphuric acid to clean its surface, then rub a little mercury over it by means of a piece of rag tied on to the end of a stick, and lastly, leave the zinc standing for a short time in a dish to catch the surplus mercury as it drains off.*

The action of the amalgamated zinc is not well understood; by some it is considered that amalgamating the zinc prevents local currents by the amalgam *mechanically* covering up the impurities on the surface of the zinc and preventing their coming into contact with the liquid.

By others it is thought that amalgamating the zinc protects it from local action by causing a film of hydrogen gas to adhere to it. This theory is based on the fact that while no action takes place when amalgamated zinc

is placed in dilute sulphuric acid at ordinary atmospheric pressure, the creation of a vacuum above the liquid causes a rapid evolution of hydrogen, which, however, stops on the re-admission of the air.

Amalgamating a zinc causes it to act as a somewhat more positive substance than before, therefore the voltage of a cell containing amalgamated

Fig. 177.—Edison caustic soda cell with barrel shape jar and multiple plate element.

zinc is slightly higher than that of a cell constructed with unamalgamated zinc.

The addition of a very small amount of zinc to mercury causes the mercury to act as if it were zinc alone, arising perhaps from the amalgam having the effect of bringing the zinc to the surface.

So-called "Dry" Cells.—It is often necessary to use cells in

places where there is considerable jarring or motion, as for automobile or marine ignition. The ordinary cell is not well adapted to this service on account of the liability of spilling the electrolyte, hence, the introduction of the so called dry cell.

A dry cell is composed of two elements, usually zinc and carbon, and a liquid electrolyte.

A zinc cup closed at the bottom and open at the top forms the negative electrode; this is lined with several layers of blotting paper or other absorbing material.

The positive electrode consists of a carbon rod placed in the center of the cup; the space between is filled with carbon—ground coke and dioxide of manganese mixed with an absorbent material. This filling is moistened with a liquid, generally sal-ammoniac. The top of the cell is closed with pitch to prevent leakage and evaporation. A binding post for holding the wire connections is attached to each electrode and each cell is placed in a paper box to protect the zincs of adjacent cells from coming into contact with each other when finally connected together to form a battery.

How a Dry Cell Works.—There is nothing mysterious about a dry cell or the manner in which it works. In its usual form a dry cell consists of *a zinc can into which are packed certain active chemical materials which combine with the zinc to produce an electrical pressure or voltage.* The voltage thus produced is the result of the chemicals used and is always the same regardless of the size of the dry cell. A new dry cell has a pressure of about 1.5 volts, and this is true whether the dry cell be a very small one like a flash light battery or a large 6 in. dry cell.

A dry cell is simply a package of electricity done up in convenient form. When you purchase a dry cell, the commodity actually bought is stored up electricity and the dry cell which gives you the most electricity for a given price is the cell you want to use.

The unit of quantity of electricity is commonly known as the ampere hour. It is the amount of electricity which will flow from a battery that is delivering one ampere for a period of one hour or one-half an ampere for a period of two hours, etc. If the number of ampere hours in a dry cell be known and also the rate at which this electricity was extracted from the cell. it would be a simple matter to find out how long the dry cell

would last. To determine this, *divide the ampere hour capacity of the dry cell by the current which it is delivering in amperes,* and the result is the number of hours that the cell will last.

In practical use it is almost impossible to apply this simple calculation to dry cells because it is very difficult to predict just how many ampere hours a dry cell will deliver.

The amount of electricity which is actually in a dry cell and the amount which can be obtained from it are two different things, and sometimes the difference is surprisingly large.

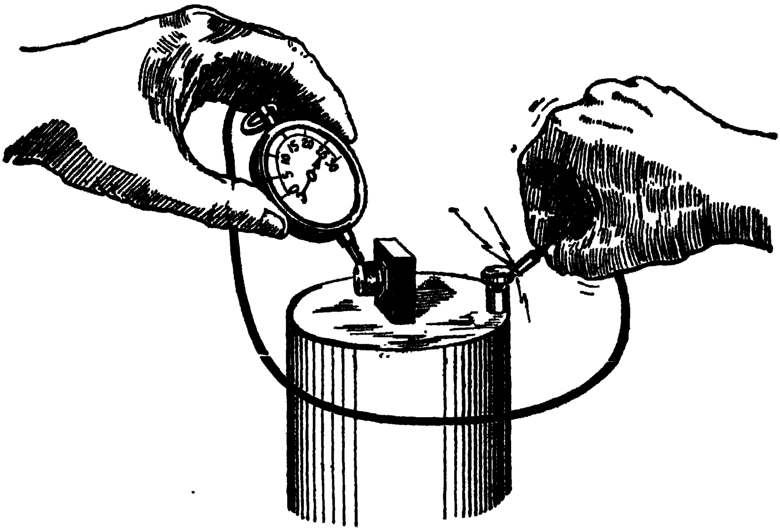


FIG. 178.—How to test a dry cell. ***Place terminal*** of ammeter on proper pole of cell and ***momentarily touch*** the other terminal with the ammeter lead. Cell should "kick" 25 to 30 amperes if fresh. Don't buy a dry cell without testing it yourself. In testing, don't hold the connection any longer than necessary to read the ammeter. If a dealer objects to cells being tested it is evidence that they are no good and that the dealer is dishonest.

The amount of electricity actually stored in a dry cell depends primarily on the size of the cell and the skill and knowledge of the manufacturer.

The amount of electricity which can be obtained from a dry cell depends very largely on the rate at which the cell is discharged, that is, the amount

of current which the battery is called upon to deliver. If the current be too small in proportion to the size of the cell, the time required to discharge it will be so great that the factor of natural depreciation, which is characteristic of all dry cells, consumes a measurable proportion of the cell's capacity, leaving less than the full amount for useful service.

On the other hand, if the current be too great for the size of cell, then the cell will be overloaded, and this, too, reduces its capacity.

Between these two extremes is a certain current drain for each size of dry cell at which it will give practically all the electricity originally stored in it by the manufacturer.

This current drain is called the normal discharge rate of the dry cell.

The larger the cell, the larger its normal discharge rate and the greater its capacity.

Points Relating to Dry Cells.—The following instructions on the care and operation of dry cells should be carefully noted and followed to get the best results:

1. In renewing dry cells (or any other kind of cell), a greater number should never be put in series than was originally required to do the work, because the additional cells increase the voltage beyond that

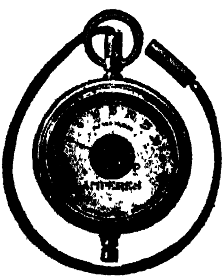


Fig. 179.—Burgess battery ammeter for testing dry cells.

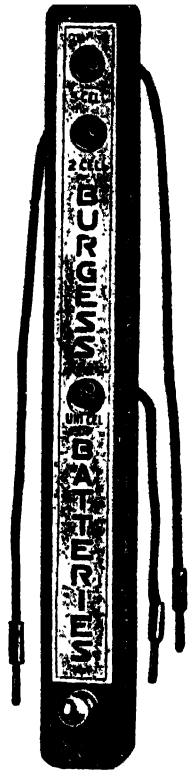


Fig. 180.—Burgess flash light battery and lamp tester. *It contains* sockets for three sizes of lamps, with a flexible lead from each socket. Thus either a two cell battery, three cell battery or a Uni-Cel can be tested without changing the lamp. Care should be used not to test a three cell battery on a two cell lamp, as the lamp is apt to be burnt out. On the other hand, if a two cell battery be tested on a three cell lamp, the battery will appear to be weak. Uni-Cels should be tested only with a one and a half volt lamp.

required, which causes more current than is necessary to flow through the coil. This increased current flow shortens the life of the battery.

2. In connecting dry cells in places where there is vibration, heavy copper wire should not be used, because vibration will cause it to break.

3. Water should not be allowed to come in contact with the paper covers of the cells because they form the insulation, hence, when moist, current will leak across from one cell to another, resulting in running down the battery.

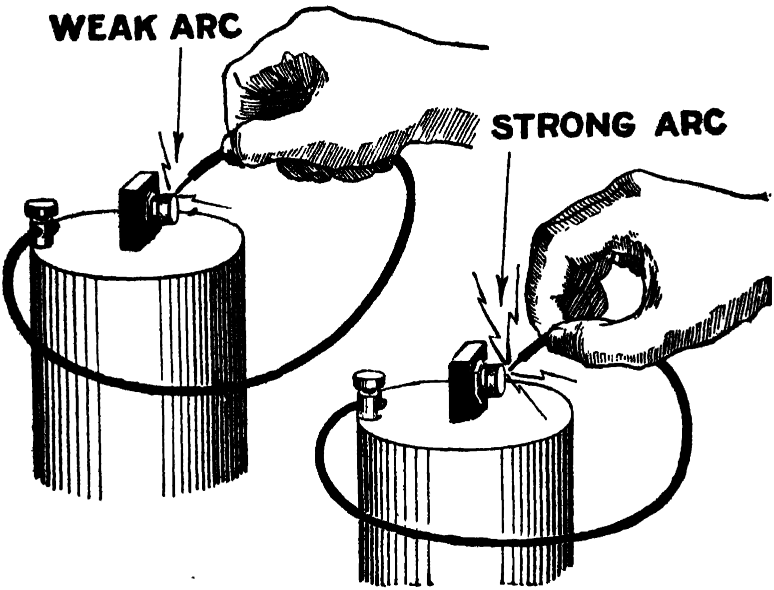


FIG. 181 and 182.—Testing cell without ammeter. A weak arc indicates a run down cell, whereas a strong arc, good condition. This test is best made in the dark and should not be relied upon in buying new cells.

4. Dry cells will deteriorate when not in use, the internal resistance increasing from .1 ohm (when new) to about .5 ohm in a year. The reason dry cells deteriorate is because the moisture evaporates. Freezing, exposure to heat, and vibration which loosens the sealing, causes the evaporation.

5. Weak cells can be strengthened somewhat by removing the paper jacket, punching the metal cup full of small holes, and then placing in a weak solution of sal-ammoniac, allowing the cells to absorb all they

will take up. This is only to be recommended in cases of emergency when they are hard to get.

6. The average voltage of a dry cell when new is one and one-half volts, while the amperage ranges from about twenty-five to fifty amperes according to size.

7. A dry cell when fresh should show from 20 to 25 amperes when tested; the date of manufacture should also be noted as fresh cells are most efficient.

8. Dry cells should be tested with an ammeter, care being taken to do it quickly as the ammeter being of a very low resistance short circuits the cell. A volt meter is not used in testing because, while the cells are not giving out current, their voltage remains practically the same, and

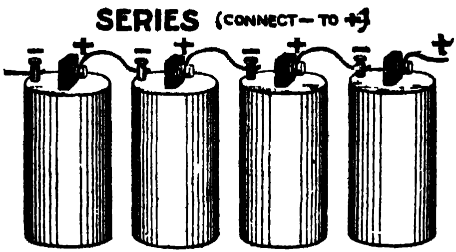


FIG. 183.—Diagram of a series battery connection: four cells are shown connected by this method. If the cell voltage be one and one-half volts, the pressure between the (+) and (–) terminals of the *battery* is equal to the product of the voltage of a single cell multiplied by the number of cells. For four cells it is equal to six volts.

a cell that is very weak will show nearly full voltage. When no ammeter is at hand, the battery current may be tested by disconnecting the end of one of the terminal wires and snapping it across the binding post of the other terminal; the intensity of the arc produced will indicate the condition of the battery.

Battery Connections.—There are three methods of connecting cells to form a battery; they may be connected:

1. In series;
2. In parallel;

NOTE—*Do not patronize any dealer who objects to a customer testing a dry cell; he is dishonest.*

3. In series parallel.

A series connection consists *in joining the positive pole of one cell to the negative pole of the other,* as shown in fig. 183.

A series connection adds the voltage of each cell; that is, the voltage of the battery will equal the sum of the voltage of each cell.

For example, connecting four cells of 1½ volts each ***in series*** will give a total of six volts.

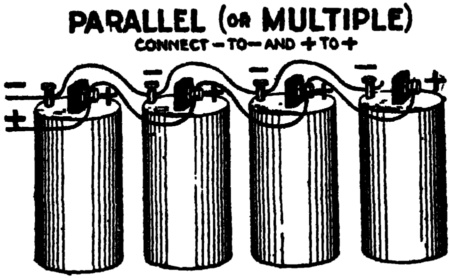


FIG. 184.—Diagram of a parallel or multiple connection. When connected in this manner the voltage of the battery is the same as that of a single cell, but the current is equal to the amperage of a single cell multiplied by the number of cells. Thus with 1½ volt 15 ampere dry cells, the combination or battery connected as shown would give 4×15=60 amperes at a pressure of 1½ volts.

A parallel or multiple connection consists *in connecting the positive terminal of one cell with the positive terminal of another cell and the negative terminal of the first cell with the negative terminal of the second cell.*

A parallel connection adds the amperage of each cell; that is,

the amperage of the battery will equal the sum of the amperage of each cell.

For instance, connecting four cells of 25 amperes each in parallel will give a total of one hundred amperes when connected in parallel.

A series parallel connection, fig. 185, consists *of two series sets of cells connected in parallel.*

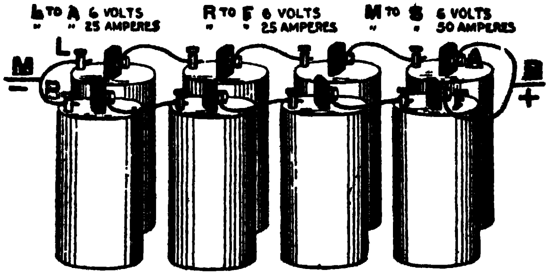


FIG. 185.—Diagram of a series parallel connection. Two sets of cells are connected in series, and the two batteries thus formed, connected in parallel. The pressure equals the voltage of one cell, multiplied by the number of cells in one battery, and the amperage, that of one cell multiplied by the number of batteries. This form of connection is objectionable unless all the cells be of equal strength. If old cells be placed on one side and new cells on the other, current will flow (as in fig. 187) from the stronger through the weaker until the pressure of all the cells thus becomes equal. This process therefore wastes some of the energy of the strong cells.

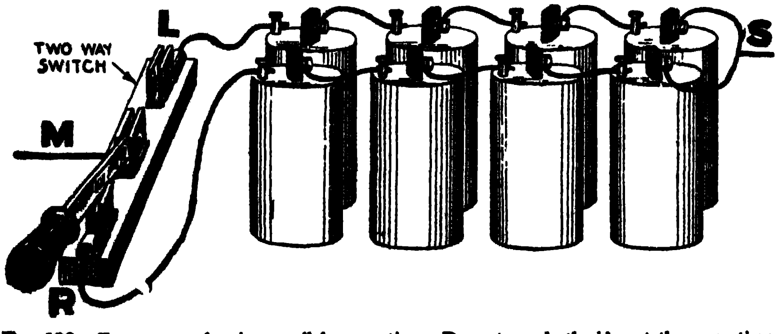


FIG. 186.—Proper use of series parallel connection. Do not use both sides at the same time. Alternate by means of a two way switch between L and R, so that one battery can recuperate while the other is being used. This is a good method for battery ignition.

The voltage of a series parallel connection is equal to the voltage of one cell multiplied by the number of cells in one battery, and the amperage is equal to the amperage of one cell multiplied by the number of batteries.

In series parallel connections the voltage of each set of cells or battery must be equal, or the batteries will be weakened, hence each battery of a series parallel connection should contain the same number of cells.

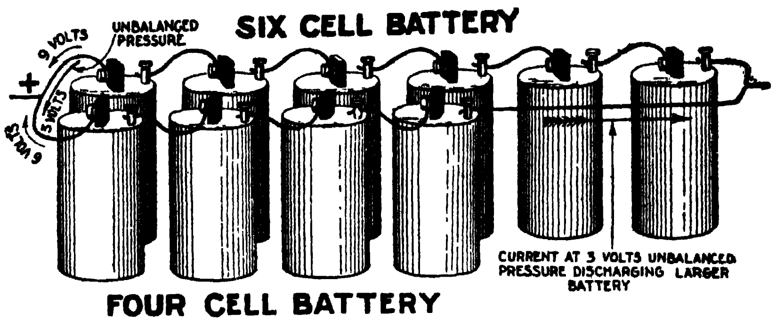


FIG. 187.—Diagram to illustrate incorrect wiring. *The current pressure* of the six cell battery being greater than that of the smaller unit, current will flow from the former through the latter until the pressure of the six cells is equal to that of the four cells.

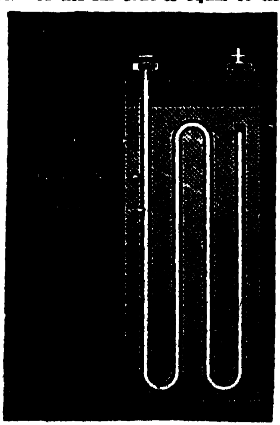
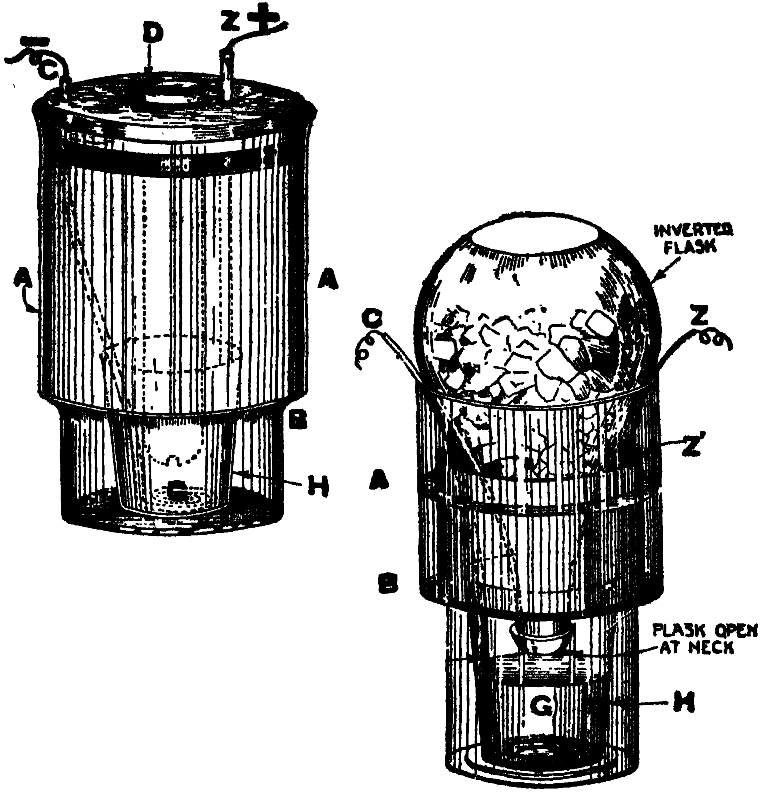


FIG. 188.—Cross section of twin dry cell showing construction. It differs from the round dry cell only in construction, the active element, zinc, is not made into a can, but is in plate form within the chemical mix, entirely encased in a heavy container, where it is subject to chemical action over its entire area and on both sides.



Figs. 189 and 190.—Two forms of Meidinger gravity cell in which no porous partition is employed, the copper sulphate and the zinc sulphate solutions being kept separated solely by the action of gravity. The zinc sulphate solution being the lighter of the two is therefore put at the top. In each cell the copper plate G, is put inside a small inner glass tumbler H, so that the particles of zinc which may become detached from the zinc plate Z, shall fall clear of the copper plate and be prevented coming into contact with it. In the type cell, shown in fig. 189, the crystals of copper sulphate are in a glass tube D, with only a small hole at the bottom; while in the type shown in fig. 190, the crystals are contained in an inverted flask open at the neck. *In both types,* contact is made with the copper plate by an insulated copper wire C. The zinc plate Z', which is in the form of a cylinder, is supported on a shoulder B, formed by a contraction of the outer glass vessel A.

Fig. 187 shows an incorrect method of making a series parallel connection. If the circuit be open, the six cells, on account of having more voltage than the four cells, will overpower them and cause a current to flow in the direction indicated by the arrows until the pressure of the six cells has dropped to that of the four. This will use up the energy of the six cells, but will not weaken the four cell battery. This action can be corrected by placing a two-way switch in the circuit at the junction of the two negative terminals so that only one battery can be used at a time, as in fig. 186.

TEST QUESTIONS

1. *What is the difference between a battery and a cell?*
2. *How are cells classified?*
3. *Describe the primary cell.*
4. *What names are given to the metal plates; to the fluid; to the end of the metal plates?*
5. *Describe the action of a cell.*
6. *Why is the polarity of an element different from that of its terminal?*
7. *Describe polarization.*
8. *Describe the internal action in a cell,* ***a,*** *when the terminals are connected externally;* ***b,*** *when not connected?*
9. *What governs the rate of flow of a cell?*
10. *What are the effects of polarization?*
11. *Give some methods of depolarizing.*
12. *What is a depolarizer; depolarizer bag?*

13. *State Volta's contact law.*
14. *Give contact series of metals,* ***a,*** *according to Volta;* ***b,*** *according to Pfaff.*
15. *Give Volta's law for contact series of metals.*
16. *State the laws of chemical action in a cell.*
17. *Name six requirements of a good cell.*
18. *What is the difference between single and two fluid cells?*
19. *How are the fluids separated in a two fluid cell?*
20. *Describe some cells which really do not belong to the single fluid class.*
21. *Name a cell largely used on bell circuits.*
22. *Describe the Leclanche cell.*
23. *Give directions for setting up a Leclanche cell.*
24. *Is a Leclanche cell used on open or closed circuit work?*
25. *State some objections to the Leclanche cell.*
26. *Describe the construction and operation of a Fuller bichromate cell; what is its voltage?*
27. *Name a cell well adapted for use on closed circuits*
28. *Describe the Bunsen and Grenet cells.*
29. *What cell is largely used on telegraph circuits?*
30. *Describe the chemical reactions which take place in the Daniell cell.*
31. *How does the Daniell gravity cell differ from the Daniell cell?*
32. *Describe the construction and operation of a so-called dry cell.*
33. *Give eight points relating to dry cells.*

34. *In the care of batteries what is very essential to obtain good results?*
35. *What is creeping?*
36. *How is a piece of zinc amalgamated?*
37. *What is the action of amalgamated zinc?*
38. *How are cells connected?*
39. *Describe, a, series; b, parallel; c, series parallel connection.*
40. *What voltage and current is obtained by the various connections?*
41. *Which form of connection is objectionable?*
42. *Give battery directions for the various cells.*

CHAPTER 5

Conductors and Insulators

Bodies differ from each other in a striking manner in the freedom with which the electric current moves upon them.

If the electric current be imparted to a certain portion of the surface of glass or wax, it will be confined strictly to that portion of the surface which originally receives it, by contact with the source of electricity; but if it be in like manner imparted to a portion of the surface of a metallic body, it will instantaneously diffuse itself uniformly over the entire extent of such metallic surface, exactly as water would spread itself uniformly over a level surface on which it is poured.*

Bodies in which the electric current moves freely are called ***conductors****, and those in which it does not move freely are called* ***insulators.***

There is, however, no substance so good a conductor as to be devoid of resistance, and no substance of such high resistance as to be a ***non-conductor.***

Mention should be made here of the misuse of the word ***non-conductor****; the so-called "non-conductors" are properly termed insulators.*

*NOTE.—***The discovery*** of this property of matter is due to Stephen Gray, who, in 1729 found that a cork, inserted into the end of a rubbed glass tube, and even a rod of wood stuck into the cork, possessed the power of attracting light bodies. He found, similarly, that metallic wire and pack thread conducted electricity, while silk did not. Gray even succeeded in transmitting a charge of electricity through a hempen thread over 700 feet long, suspended on silken loops. A little later, Du Fay succeeded in sending electricity to no less a distance than 1,256 feet through a moistened thread, thus proving the conducting power of moisture. From that time the classification of bodies into conductors and insulators has been observed.

The bodies named in the following series possess conducting power in different degrees in the order in which they stand, the most efficient conductor being first, and the most efficient insulator being last in the list.

Table of Conductors and Insulators

Good Conductors	*Fair Conductors*	*Partial Conductors*	*Insulators*
Silver	Charcoal and coke	Water	Slate
Copper	Carbon	The body	Oils
Aluminum	Plumbago	Flame	Porcelain
Zinc	Acid solutions	Linen	Dry paper
Brass	Sea water	Cotton	Silk
Platinum	Saline solutions	Mahogany	Sealing wax
Iron	Metallic ores	Pine	Gutta percha
Nickel	Living vegetable substances	Rosewood	Ebonite
Tin		Lignum Vitæ	Mica
Lead	Moist earth	Teak	Glass
		Marble	*Dry* air

The earth is a good conductor; much difficulty is frequently experienced by the wires making contact with some substance that will conduct the electricity to the earth. This is called "grounding."

Mode of Transmission.—*The exact nature of electricity is not known, yet the laws governing its action, under various conditions are well understood,* just as the laws of gravitation are known, although the constitution of gravity cannot be defined.

Electricity, though not a substance, can be associated with matter, and its transmission requires energy. While it is neither a gas nor a liquid, its behavior sometimes is similar to that of a fluid so that it is said to "flow" through a conductor. The expression *flowing* does not really mean that

NOTE.—*Copper is pre-eminently* the metal used for electric conduction, being among the best conductors, it is excelled by one or more of the other metals, but no other approaches it in the average of all qualities.

there is an actual movement in the wire, similar to the flow of water in a pipe, but is a convenient expression for the phenomena involved.

Effect of Heat —*The conducting power of bodies is affected in different ways by their temperature.* In the metals it is diminished by elevation of temperature; but in all other bodies, and especially in liquids, it is augmented. Some substances, which are insulators in the solid state, become conductors when fused.

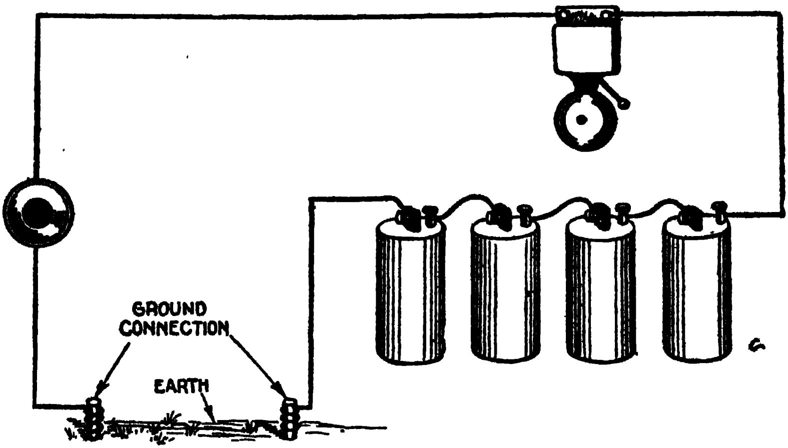


FIG. 191.—Ordinary electric bell installation with ground return illustrating the earth as a conductor.

Sir H. Davy found that glass raised to a red heat became a conductor; and that sealing wax, pitch, amber, shellac, sulphur, and wax, became conductors when liquefied by heat.

Heating Effect of the Current.—If a current of electricity pass over a conductor, no change in the heat condition of the conductor will be observed as long as its transverse section is so considerable as to leave sufficient space for the free passage of the current.

FIGS. 192 and 193.—Acme bias tape. Fig. 192, sewed bias; fig. 193, seamless bias. Colors: yellow or black. Cut: bias, without seams; standard finish; yellow, dry; black, greasy. Standard rolls: 72 linear yds ½ gross yds. Any width ½ in. to 36 ins. Standard core 1½ ins. ⅜ in. optional.

If this thickness be diminished, or the quantity of electricity passing over it be augmented, or, in general, if the ratio of the electricity to the magnitude of the space afforded to it be increased, the conductor will be found to undergo an elevation of temperature, which will be greater, the greater the quantity of the electricity and the less the space supplied for its passage.

These heat effects are manifested in different degrees in different metals, according to their varying conducting powers.

The poorest conductors, such as platinum and iron, suffer much greater changes of temperature by the same charge than the best conductors, such as gold and copper.

The charge of electricity, which only elevates the temperature of one conductor a small amount, will sometimes render another incandescent, and will vaporize a third.

NOTE.—***The question of temperature*** bears an important part in all tests and calculations of electrical conductors, as the resistance varies directly with temperature. The resistance of copper wire increases about twenty-three one-hundredths and that of iron wire about twenty-eight one-hundredths per cent. for each additional degree F. The following average values of the temperature coefficient have been found experimentally, at 32° Fahr.

Metals	*Fahrenheit*
Aluminum	.0022
Copper, annealed	.0023
Gold	.0021
Mercury	.0004
Platinum	.0014
Silver, annealed	.0022
Soft iron	
Tin	.0025
Zinc	.0023

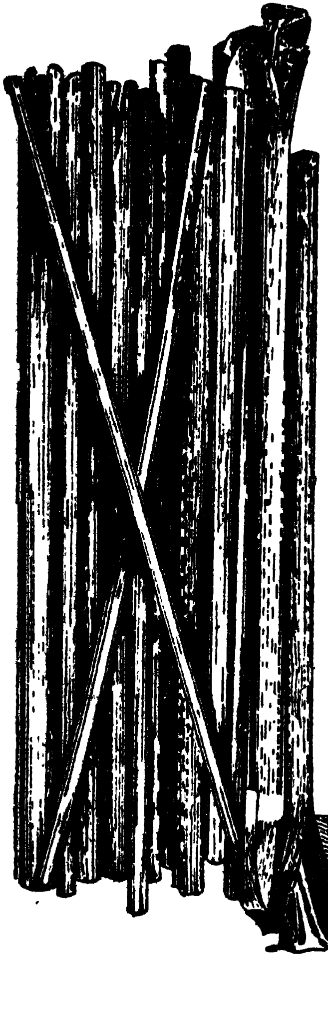


Fig. 194.—Acme high voltage tubing designed for transformer leads, primary and secondary, and for insulating heavy wires. Mechanically it is strong and resists abrasion and electrically it can be made to stand voltages up to 30,000. This tubing is a combination of Acme varnished cambric and a heavy, closely braided cotton sleeving saturated with multiple coats of Acme wire insulating varnish and each coat baked. Made in yellow or black. Inside diameters from ¼ to 1½ ins., 36 ins. long. The number of wraps of cambric is determined by the voltage requirements.

Insulators.—The term insulator is used in two ways:

1. As an insulating substance or medium, and

2. As a specially formed piece of some insulating material, such as glass, porcelain, etc. No substance has the power of absolutely preventing the passage of electric currents between conductors but many have sufficient insulating power for practical purposes.

The properties to be desired in a good insulating material are:

1. Permanence;

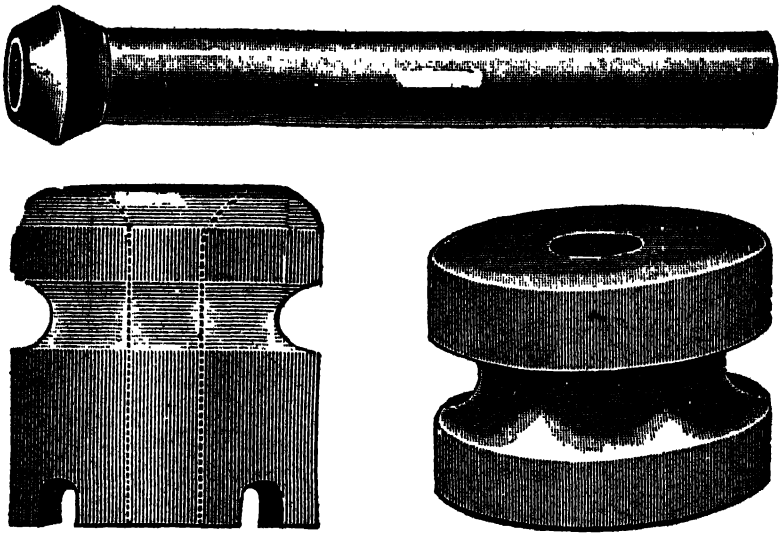
2. High power of resistance to breakdown;

3. Mechanical strength;

4. Fairly high dielectric or insulation resistance;

5. Special qualities for the use to which the material is to be put.

Permanence is the most important quality, and is the one least easily attained. The power of resisting breakdown is a complex quality, for it is not solely dependent on mere puncturing pressure, but also on mechanical goodness, and to a certain extent on the insulation resistance. It cannot be easily determined by a simple laboratory test, but must be found by experience of actual service conditions.



Figs. 195 to 197.—Porcelain insulators. Fig. 195, tube type; figs. 196 and 197 grooved insulators.

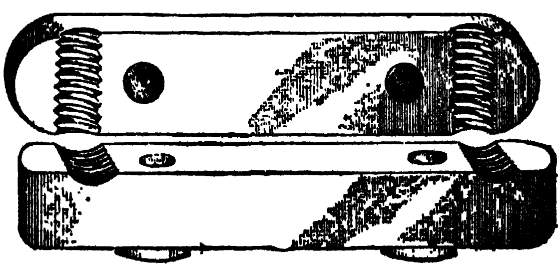


Fig. 198.—Two wire porcelain cleat.

Impregnating Compounds.—These are used for the treatment of fibrous materials. They increase the insulating properties of the fibrous materials, render them moisture proof and able to withstand the effect of heat with less rapid deterioration.

When wires or cables are to be used under water, they must be made impervious, and great care must be taken to prevent the water penetrating and thus injuring the insulation.

Water as a Conductor.—Water, whether in the liquid or vaporous form, is a conductor, though of an order greatly inferior to the metals. This fact is of great importance in electrical phenomena. The atmosphere contains, suspended in it, always more or less aqueous vapor, the presence of which impairs its insulating property.

The best insulators become less efficient if their surface be moist, the electricity passing by the conducting power of the moisture. This circumstance also shows why it is necessary to dry previously the bodies on which it is desired to develop electricity by friction.

TEST QUESTIONS

1. *What is the difference between a conductor and an insulator?*
2. *Why should the word non-conductor not be used?*
3. *Give a list of a, good conductors; b, fair conductors; c, partial conductors; d, insulators.*
4. *What is understood by the term grounding?*
5. *What metal is pre-eminently the metal for conductors?*
6. *What is understood by the expression "flowing" as applied to the current?*

7. *What is the effect of heat on conductors?*
8. *Describe the heating effect of the current.*
9. *What properties are to be desired in a good insulating material?*
10. *What is an impregnating compound and what is its use?*

CHAPTER 6

Resistance and Conductivity

Resistance is that property of a substance that opposes the flow of an electric current through it.

The practical electrician has to measure electrical resistance, pressure, and the capacity of condensers. Each of these

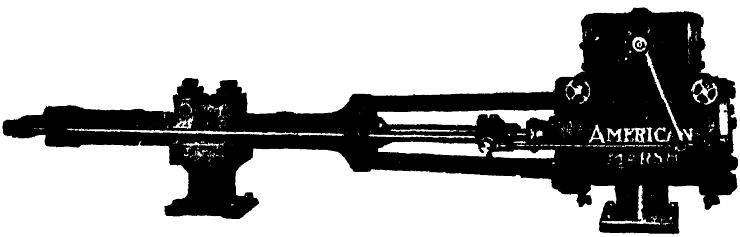


FIG. 199.—Hydraulic analogy of *resistance*. The hydraulic pump here shown with its steam cylinder of very large diameter as compared with the water cylinder is capable of pumping water against great pressure which opposes its flow. *Similarly*, a dynamo pumps electricity through a circuit which opposes more or less its flow, this opposition being called *resistance*.

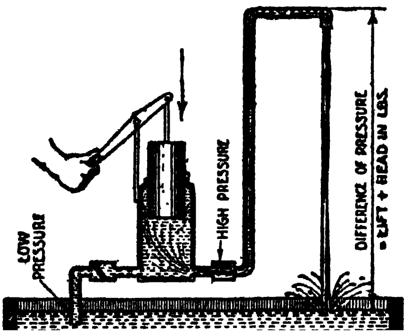
several quantities is measured by comparison with ascertained standards, the particular methods of comparison varying, however, to meet the circumstances of the case.

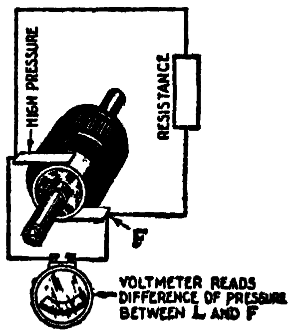
Ohm's law states that *the strength of a current due to an electric pressure falls off in proportion as the resistance in the circuit increases*.

It is therefore possible to compare two resistances with one another by finding out in what proportion each will cause the current of a constant battery to fall off.

Silver is taken as the standard, with the percentage of 100, *and the conductivity of all other metals is expressed in hundredths of the conductivity of silver.*

Conductivity of Metals and Liquids.—The metals in general, conduct well, hence their resistance is small, but metal





FIGS. 200 and 201.—Hydraulic analogy illustrating pressure. When the pump is operated the water is forced up from a low level (low pressure) to a high level producing high pressure; whence from the end of the pipe it falls back by gravity to the low level. *Similarly,* in fig. 201, the dynamo forces up electricity from a low pressure to a high pressure by interposing a resistance in the circuit passing through the resistance its pressure falls to low pressure. *The author objects to the term "potential" commonly used in place of pressure as the simple word pressure is more easily understood.*

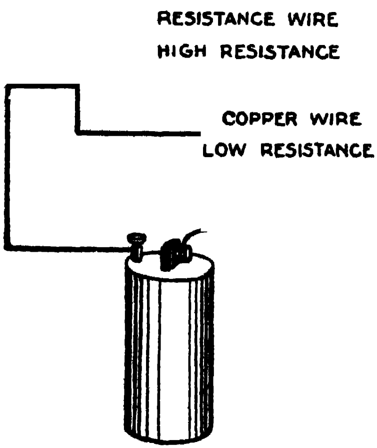
wires must not be too thin or too long, or they will resist too much, and permit only a feeble current to pass through them.

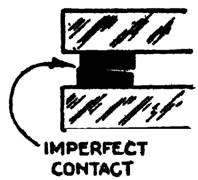
NOTE.—*A current of electricity* always flows in a conducting circuit when its ends are kept at different potentials, in the same way that a current of water flows in a pipe when a certain pressure is supplied. The same electrical pressure does not, however, always produce a current of electricity of the same strength, nor does a certain pressure of water always produce a current of water of the same volume or quantity. In both cases the strength or volume of the currents is dependent, not only upon the pressure applied, but also upon the *resistance* which the conducting circuit offers to the flow in the case of electricity, and on the friction (which may be expressed as resistance) which the pipe offers to the flow in the case of water.

The liquids in the battery do not conduct nearly so well as the metals, and different liquids have different resistances. Pure water will hardly conduct at all, unless the voltage be very high.

Salt and saltpetre dissolved in water are good conductors, and so are dilute acids, though strong sulphuric acid is a bad conductor. Gases are bad conductors.

Effect of Heat.—Another very important fact concerning the resistance of conductors is that *the resistance in general increases with the temperature.*





FIGS. 202 and 203.—Examples of Resistance, fig. 202, resistance due to material of conductors; fig. 203, resistance due to imperfect contact. Here poor ignition results from the imperfect or reduced area of contact of the breaker points when not filed true increasing the resistance of the primary spark and reducing strength of the spark in secondary circuit at break.

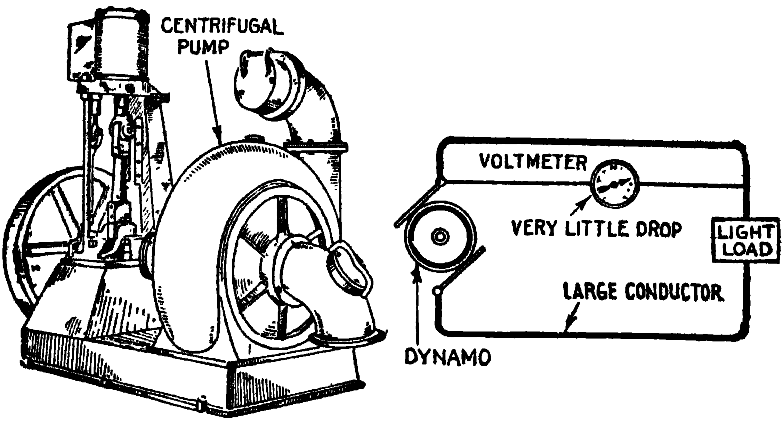
While this fact is true regarding metals, it does not apply to non-metals. The resistance of different metals does not increase in the same proportion. Iron at 100 degrees C, has lost 39 per cent. of the conducting power it possessed at zero, while silver loses but 23 per cent.

Laws of Electrical Resistance.—Resistances in a circuit may be of two kinds:

1. Resistance of the conductors;
2. Resistance due to imperfect contact.

The latter kind of resistance is affected by pressure, for when the surfaces of two conductors are brought into more intimate contact the current passes more freely from one conductor to the other.

The following are the laws of the resistance of conductors:



FIGS. 204 and 205.—Hydraulic analogy of *conductivity*. The direct connected centrifugal pump set (fig. 204) with its small engine and large pump suggests the pumping of a large volume of water against low pressure—*easy flow*. *Similarly*, in fig. 205, a dynamo having an external circuit of very large copper wires "pumps" the electricity against very little resistance, thus a volt meter connected as shown would show very little drop indicating high conductivity. Now if resistance wires were substituted for the copper wires, the voltmeter would show a large drop indicating low conductivity.

1. *The resistance of a conducting wire is proportional to its length.*

If the resistance of a mile of telegraph wire be 13 ohms, that of fifty miles will be $50 \times 13 = 650$ ohms.

2. *The resistance of a conducting wire is inversely proportional*

to the area of its cross section, and therefore in the usual round wires *is inversely proportional to the square of its diameter*.

Ordinary telegraph wire is about ⅙th of an inch thick; a wire twice as thick would conduct four times as well, having four times the area of cross section; hence an equal length of it would have only ¼th the resistance.

3. *The resistance of a conducting wire of given length and thickness depends upon* the material of which it is made—that is, upon the specific resistance *of the material*.

Conductance and Conductivity.—It is sometimes convenient, if not necessary, to make use of the *conductance*, or a circuit, and the *conductivity* of a material.

The conductance of a circuit is the reciprocal of its resistance. The conductivity of a material is the ratio, expressed in per cent, of its conducting power to the conducting power of a standard, often *pure copper*, whose conductivity is called 1, or 100 per cent.

Example.—A circuit consists of a battery whose resistance is 2 ohms in series with two resistances of 10 ohms and 15 ohms respectively. Find the conductance of the circuit.

Solution.—Since all parts are in series, the total resistance is the sum of all parts, hence

$$\text{resistance} = 2+10+15 = 27 \text{ ohms},$$

Therefore conductance $= \frac{1}{27} = .037$.

Specific Conductivity.—The figure which indicates the relation between one substance and another as to their capacity to conduct electricity is called *specific* or *relative conductivity*. Taking the specific conductivity of silver as 100, that of pure copper is 96.

The specific resistance of a substance is the reverse of its relative conductivity. The specific resistance of a metal is generally expressed in millionths of an ohm as the resistance of a centimeter cube of that metal between opposite sides.

The following table gives the data for a few metals:

Substance	*Specific resistance in microhms*	*Specific conductivity*
Silver	1.609	100
Copper	1.642	96
Gold	2.154	74
Iron (soft)	9.827	16
Lead	19.847	8
German silver	21.470	7.5
Mercury (liquid)	96.146	1.6

The specific resistance of copper is therefore:

$$\frac{1.642}{1{,}000{,}000} \text{ ohms, or } 1.642 \text{ microhms.*}$$

Divided Circuits.—If a circuit be divided, as in fig. 206, into two branches at A, uniting again at B, the current will also be divided, part flowing through one branch and part through the other.

The relative strength of current in the two branches will be proportional to their conductivities.

This law will hold good for any number of branch resistances connected between A and B. Conductivity is, as shown before, the reciprocal of resistance.

Example.—If, in fig. 206, the resistance of R = 10 ohms, and R′ = 20 ohms, the current through R will be to the current through R′, as $\frac{1}{10}$ to $\frac{1}{20}$;

*NOTE. The prefixes "*meg*" and "*micro*" denote million and millionth. ***For example*** a megohm equals 1,000,000 ohms, a microhm equals $\frac{1}{1.000,000}$ of an ohm.

or, as 2:1, or, in other words, ⅔ of the total current will pass through R, and ⅓ through R′. The joint resistance of the two branches between A and B, will be less than the resistance of either branch singly, because the current has increased facilities for travel. In fact, the joint conductivity will be the sum of the two separate conductivities.

Taking again the resistance of R = 10 ohms and R′ = 20 ohms, the joint conductivity is

$$\frac{1}{10}+\frac{1}{20}=\frac{3}{20}$$

and the joint resistance is equal to the reciprocal* of $\frac{3}{20}$ or 6⅔.

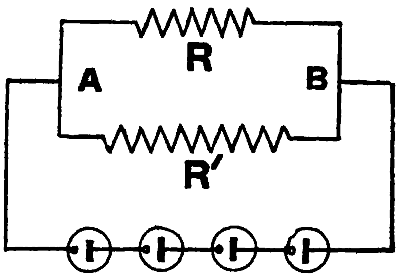


FIG. 206.—Divided circuit with two conductors *in parallel.*

In most cases the resistance of the different branches will be alike. This simplifies the calculations considerably. Take, for instance, two branches of 100 ohms resistance each and find the joint resistance.

Solution: $\frac{1}{100}+\frac{1}{100}=\frac{2}{100}$; the reciprocal is $\frac{100}{2}$ = 50 ohms, or, in other words, the joint resistance is one-half of the resistance of a single branch, and each branch, of course, will carry one-half of the total current in amperes.

*NOTE.—*The reciprocal of a number* is equal to 1 ÷ the number; for instance the reciprocal of $\frac{3}{20} = 1 \div \frac{3}{20} = \frac{20}{3} = 6⅔$

With three branches of equal resistance, the joint resistance will be $\frac{1}{3}$, with four branches $\frac{1}{4}$; with 100 branches $\frac{1}{100}$ of the resistance of a single branch.

If, for instance, the resistance of an incandescent lamp hot be 180 ohms, the joint resistance of 100 such lamps connected in parallel is

$$\frac{180}{100} = 1.8 \text{ ohms.}$$

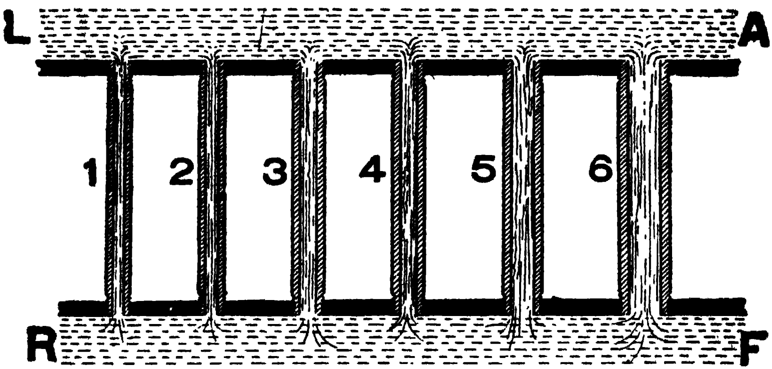


FIG. 207.—Hydraulic analogy for divided circuits. *In the system* of pipes shown, water flows from **LA**, to **RF**, through the six vertical pipes 1 to 6, the greatest amount going through the one which offers the least resistance. If pipes 1 to 6, all have the same dimensions, equal quantities of water will flow through them. It follows that *the resistance which the water encounters diminishes with the increase in the number of pipes between* **LA**, *and* **RF**. The electrical circuit presents the same conditions: the greater the number of parallel connections (corresponding to the pipes 1 to 6) the less is the resistance encountered by the current.

If the voltage of the system is to be, say 110 volts, then, according to Ohm's law, the current for 100 lamps is:

$$\frac{110}{1.8} = 61.11 \text{ amperes.}$$

giving for each lamp a current of

$$\frac{110}{180} = .61 \text{ ampere.}$$

In the case of two branches only, the following rule may be applied also:

Multiply the two resistances and divide the product by their sum.

Written as a formula:

$$\text{Joint resistance} = \frac{R \times R'}{R + R'}$$

Again, assuming that $R = 10$ ohms and $R' = 20$ ohms:

$$\text{Joint resistance } \frac{10 \times 20}{10 + 20} = \frac{200}{30} = 6\tfrac{2}{3} \text{ ohms.}$$

This rule *cannot* be employed for more than two branches at a time.

Example.—A current of 42 amperes flows through three conductors in *parallel* of 5, 10 and 20 ohms resistance respectively. Find the current in each conductor.

Solution.—Joint Conductance $= \frac{1}{5} + \frac{1}{10} + \frac{1}{20} = \frac{7}{20}$.

Supposing the current to be divided into 7 parts, 4 of these parts would flow in the first conductor 2 in the second and 1 in the third.

The whole current is 42 amperes.

$$\tfrac{4}{7} \text{ of } 42 = 24.$$
$$\tfrac{2}{7} \text{ of } 42 = 12.$$
$$\tfrac{1}{7} \text{ of } 42 = 6.$$

$$\left.\begin{array}{l}\text{Current in first conductor} = 24 \text{ amperes.} \\ \text{" \quad " second \quad " \quad} = 12 \text{ \quad "} \\ \text{" \quad " third \quad " \quad} = 6 \text{ \quad "}\end{array}\right\} \text{ Ans.}$$

EXAMPLES ON OHMS LAW.

Example.—Determine (a) the combined resistance and (b) the total current taken by the circuit shown in fig. 207a.

(a) The resistance of the combination may be found as follows:

$$\frac{1}{R}=\frac{1}{10}+\frac{1}{500}+\frac{1}{100}=\frac{56}{500}$$

$$R=\frac{500}{56}=8.93 \text{ ohms}$$

(b) The total current is therefore:

$$I=\frac{110}{8.93}=12.3 \text{ amperes}$$

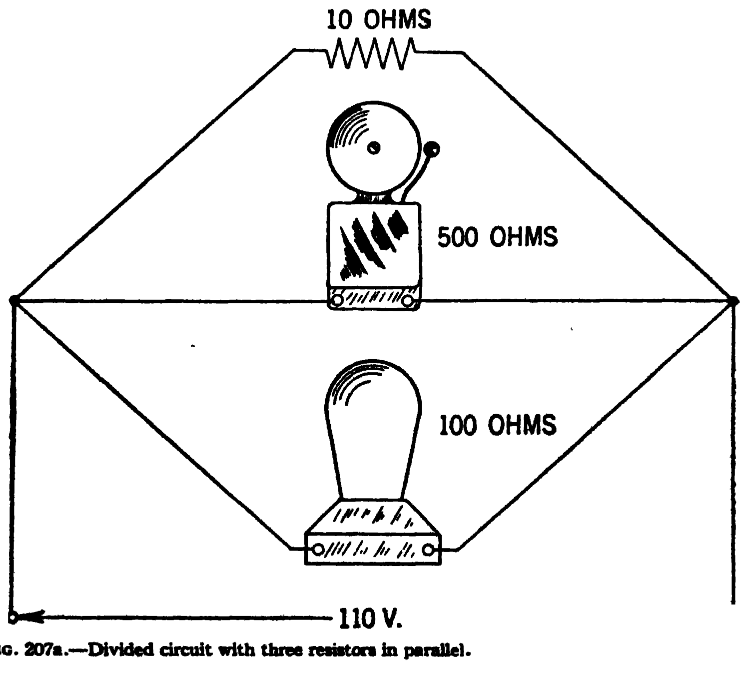


FIG. 207a.—Divided circuit with three resistors in parallel.

Example.—In the circuit shown in fig. 207b find the following:

1. The combined resistance of the circuit.
2. The current in each branch.
3. The amount of watts dissipated in each one of the resistors.

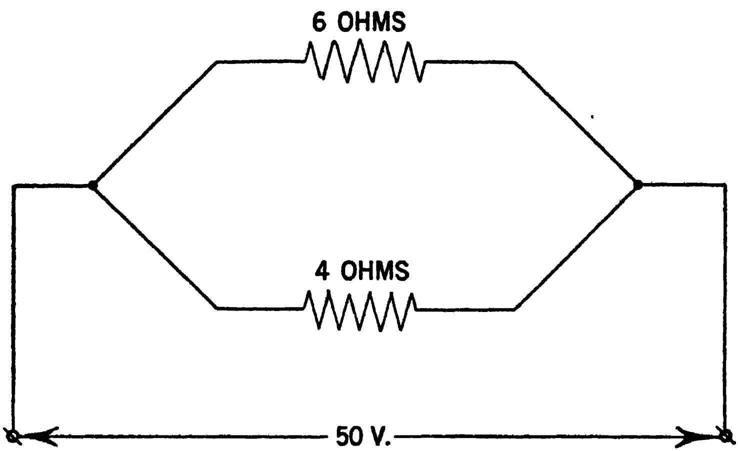


FIG. 207b.—Divided circuit with two resistors in parallel.

Example.—Fig. 207c shows an unknown resistance R, a 25 ohms electric iron and a 6 ohms electric heater connected in parallel across the terminal of a 110 volt source which supplies 25 amperes. Determine the value of the unknown resistance.

The voltage across resistance R is 110 volts. To find the value of R, the current through it must first be known. However, before this current can be determined, the current through the other two branches must be found.

Through the 6 ohms branch there is $\frac{110}{6}$ or $18\frac{1}{3}$ amperes, and through the 25 ohms branch there is $\frac{110}{25}$ or 4.4 amperes.

The current through the unknown resistance $I_x = 25 - 18\frac{1}{3} - 4.4 = 2.27$ amperes.

The value of the unknown resistance

$$R = \frac{110}{2.27} = 48.5 \text{ ohms approximately.}$$

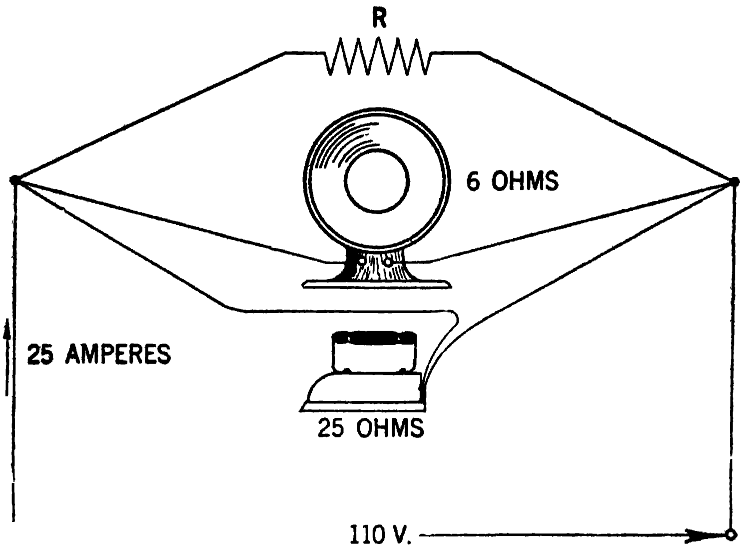


FIG. 207c.—Divided circuit with three resistors in parallel.

Example.—In circuit shown in fig. 207d determine the following:

1. The combined resistance of the circuit.

2. The current in each branch when the potential across the circuit is 120 volts.

3. The current in the main wires.

4. The amount of watts supplied by the generator.

5. If the bell is replaced by an electric iron having a resistance of 20 ohms, how many amperes will then be supplied by the generator?

6. How many watts are dissipated in the electric iron?

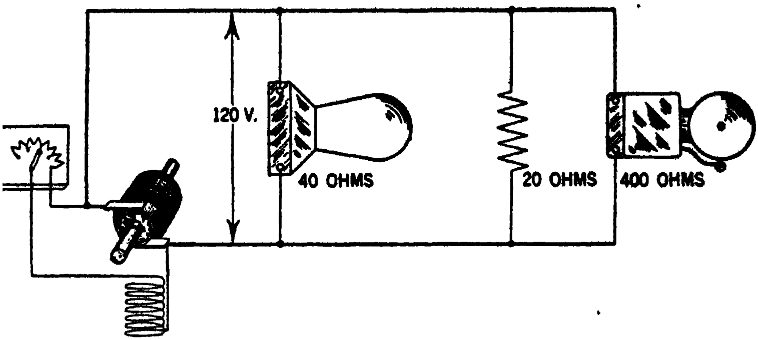


FIG. 207d.—Parallel connected load across generator terminal.

Example.—In the lighting system shown in fig. 207e each lamp takes 1 ampere at 110 volts. If the resistance of each one of the line wires is 0.5 ohms, what will be the voltage at the generator?

The current through the line wires will be 3×1 or 3 amperes.

The drop in voltage (IR drop) in each one of the line wires is $3\times0.5=$ 1.5 volts.

The voltage across the generator terminal is $1.5+110+1.5=113$ volts. Thus the generator must supply 113 volts to force the current through the line wires and lamps.

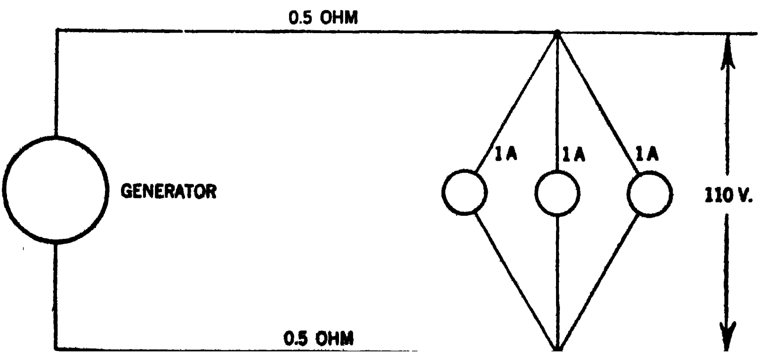


FIG. 207e.—Parallel connection of three remotely located lamps.

When solving problem of this nature, proceed as follows:

1. Determine the current through each section of the circuit.
2. Determine the voltage across each section.
3. Combine the voltages according to the rates for series circuits.

Example.—If the voltage across the generator, fig. 207f, is 115 volts, and the current taken by lamp L_1, and L_2 is 2 and 1.8 amperes respectively, find the voltage across each lamp, when the resistance of each one of the line wires between the generator and lamps is as shown.

The current between the generator and lamp L_1 will be 3.8 amperes.

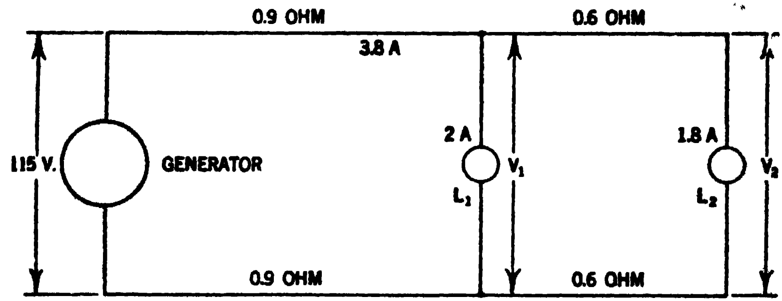


FIG. 207f.—Parallel connection of two remotely located lamps.

The voltage drop between the generator and lamp L_1 is $2 \times 0.9 \times 3.8 = 6.84$ volts.

Hence the voltage across lamp L_1 is $115 - 6.84 = 108.16$ volts.

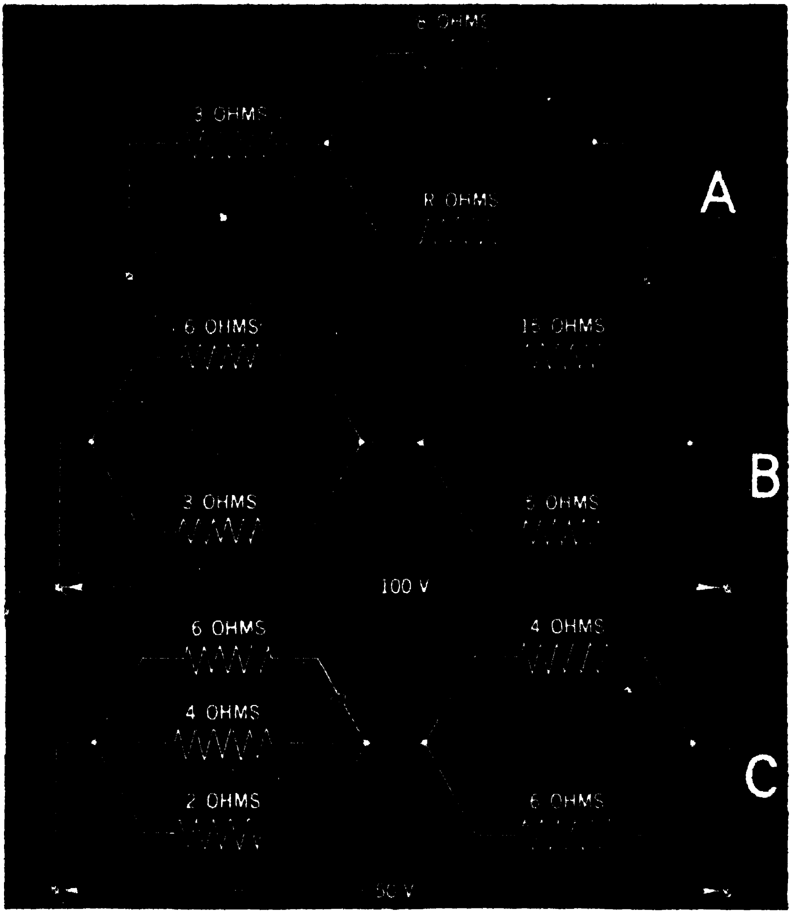
The voltage drop between the lamps is $2 \times 0.6. \times 1.8 = 2.16$ volts and finally the voltage across lamp L_2 will be $108.16 - 2.16 = 106$ volts.

Example.—In circuit shown in (A) on the opposite page the total series and combined resistances in the circuit is 10 ohms. Find resistance R, and the equivalent resistance of the branch circuits.

If the current in the main circuit be 6 amperes how many amperes will be flowing in each branch?

In circuit (B) opposite page, determine:

(a) The combined resistances, (b) total current, and (c) current in each branch circuit, when the voltage across the terminals is 100 volts.



The voltage across the terminal of circuit shown in (C) is 50 volts.

Determine: (a) the combined resistances of each branch, (b) the total current, (c) the current through each branch, and (d) the voltage drop each branch.

SERIES PARALLEL CIRCUITS.

The solution of circuit shown on opposite page is in reality very simple if it be kept in mind that any number of resistances connected in series may be replaced by a single resistor with a value equal to the arithmetical sum of the individual resistors, or that any number of resistors in parallel can be replaced by an equivalent whose value is equal to the reciprocal of the sum of the reciprocals of the individual units.

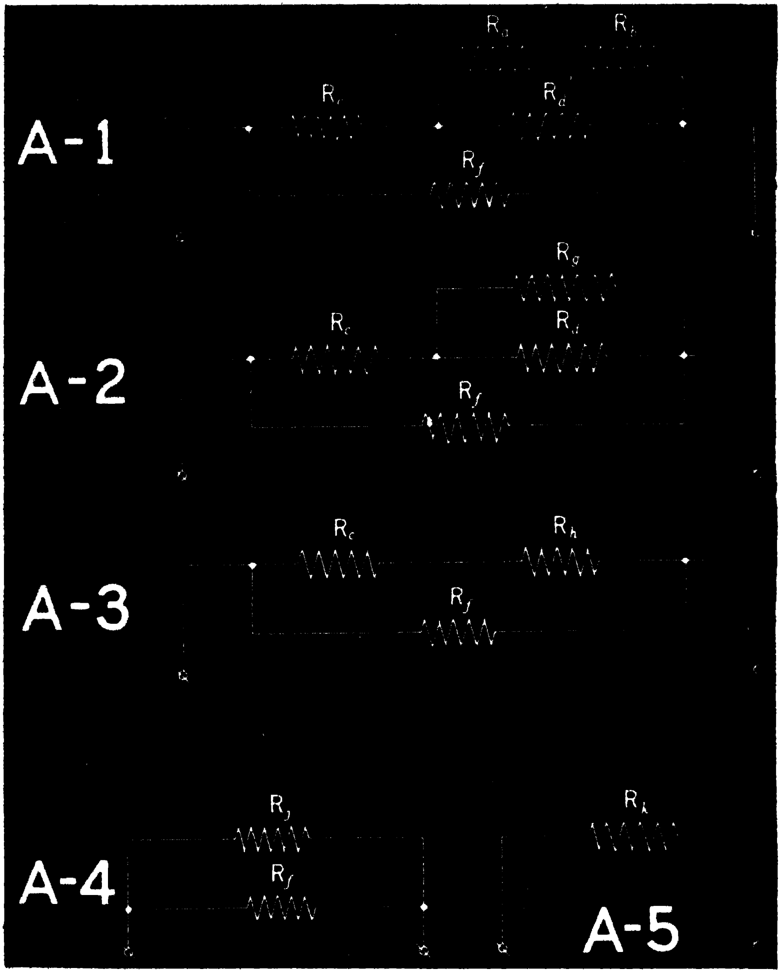
Circuit A-1 consists of resistors R_a and R_b in series, and the two also in parallel with R_d. This group is connected in series with R_c and the whole combination is again connected in parallel with R_f.

The simplest way to solve a resistance combination of this type is to remember the foregoing and to go through the problem step by step, combining each series and each parallel group and to replace them with their equivalent resistance.

Hence, to solve this circuit first replace R_a and R_b by their equivalent R_g.

The next step is to combine R_g and R_d replacing them by their equivalent R_h. By replacing R_c and R_h by their equivalent R_j, the original circuit now being reduced to the form as shown in fig. A-4.

In the manner similar to that already described R_j and R_f in parallel is replaced by a resistance R_k obtaining the result as shown in fig. A-5. Finally as a result of these calculations a resistance is obtained having the same current limiting effect as that shown in fig. A-1.



Method illustrating how a series parallel resistance combination of type shown in *A*-1 may be reduced to the simple form of that shown in fig. A-5.

TEST QUESTIONS

1. *What is resistance?*
2. *What must a practical electrician measure?*
3. *What does Ohm's law state with respect to resistance?*
4. *What is conductivity?*
5. *How does the conductivity of metals and liquids compare?*
6. *What is the standard of conductivity?*
7. *What is the effect of heat with respect to resistance?*
8. *State the laws of electrical resistance.*
9. *What is the distinction between inductance and conductivity?*
10. *Find the specific conductivity.*
11. *Give the specific resistance and specific conductivity of various metals.*
12. *What is a divided circuit?*
13. *What governs the relative strength of current in the branches of a divided circuit?*

CHAPTER 7

Electrical and Mechanical Energy

The production of electricity is simply *a transformation of energy from one form into another*, usually mechanical energy is changed into electrical energy and a dynamo is simply a device for effecting the transformation.

Prof. Fessenden truly remarks there are two independent properties of matter—gravity and inertia—and these give two ways of defining force and energy.

It should always be remembered that electricity is something real, although not easily defined. While it is not matter and is also not energy, yet under proper conditions (it having the power of doing work) it is convenient to speak of its performances as electric energy. The following questions and answers, although few in number, may present the subject with clearness.

Ques. What is energy?

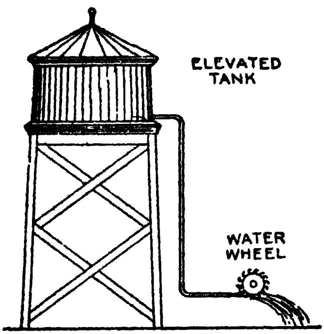
Ans. Energy is the capacity for doing work.

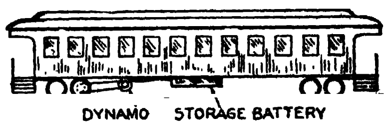
Steam under pressure is an example, a spring bent ready to be released is another form, again, water stored in an elevated tank has capacity

for doing work. These examples illustrate ***potential energy***, as distinguished from ***kinetic energy***. Potential energy may be defined as ***energy due to position***, and kinetic energy, as ***energy due to momentum***.

Ques. What is matter?

Ans. Matter is anything occupying space, and which prevents other matter occupying the same space at the same time.





FIGS. 208 and 209.—Potential, and kinetic energy. In fig. 208, the water stored in the elevated tank possesses energy by virtue of its position; being higher than the water wheel, the water will flow by gravity through the pipe and do work on the wheel. Thus, the potential energy of the water at rest in the tank, is, when it flows through the pipe converted into kinetic energy which is spent on the wheel. Fig. 209 represents a railway car with axle lighting system. If the car be set in motion and then no further power be applied, its momentum or kinetic energy will drive the dynamo which in turn will charge the storage battery, and acting like a brake will gradually bring the car to rest. During this operation, the kinetic energy, originally possessed by the moving car, is absorbed by the dynamo (neglecting friction) and delivered to the battery as electrical energy which may be used in lighting the car

Ques. What name is given the smallest quantity of matter which can exist?

Ans. The atom.

An atom means that which cannot be cut, scratched, or changed in form and that cannot be affected by heat or cold or any known force; although inconceivably small, atoms possess a definite size and mass.

Ques. What is a molecule?

Ans. A molecule is composed of two or more atoms.

Ques. What is the behavior of these minute bodies?

Ans. They are perpetually in motion, vibrating with incredible velocities.

Ques. Why at this point are definitions of energy and of matter most useful?

Ans. Because, as stated, all electric action is an exhibition of energy, and energy must act through matter as its medium.

Ques. What is the difference between electricity and magnetism?

Ans. The ultimate nature of neither is known. There are, however, some differences. To sustain a current of electricity requires energy. To sustain magnetism requires no energy. A current of electricity is always accompanied by a magnetic field of peculiar form. Magnetism alone cannot produce electricity. Electricity can do work; but magnetism cannot in the same sense—and alike with electricity, neither can it exist without contact with matter.

Ques. How is energy transmitted from one part of a material substance to another?

Ans. Gradually and successively. It requires a medium and also time.

Ques. What is the principal use or function in mechanics of electricity?

Ans. It is purely that of transmission. It corresponds to ropes, shafts and fluids as a medium of conveying and translating power, light, or heat.

Ques. What is work?

Ans. Work is the overcoming of resistance through a certain distance.

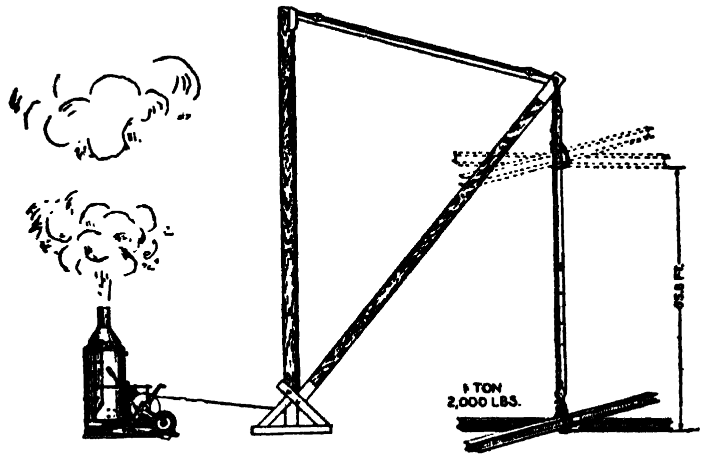


FIG. 210.—The fusion of ice, illustrating the *work done when a pound of ice at 32° Fahr. is melted or converted into water at the same temperature.* The latent heat of fusion being 143.57 heat units, and since one heat unit is equivalent to 778 ft. lbs. the work done during the fusion of one pound of ice is 778 × 143.57 = 111,698 ft. lbs. This is approximately equivalent to the work done when a hoisting engine hoists 2,000 lbs. a distance of 55.8 ft. as shown in the illustration.

As a quantity of water moving from a higher to a lower level will do work, so also will a quantity of electricity falling through a difference of pressure.

Ques. How is work measured?

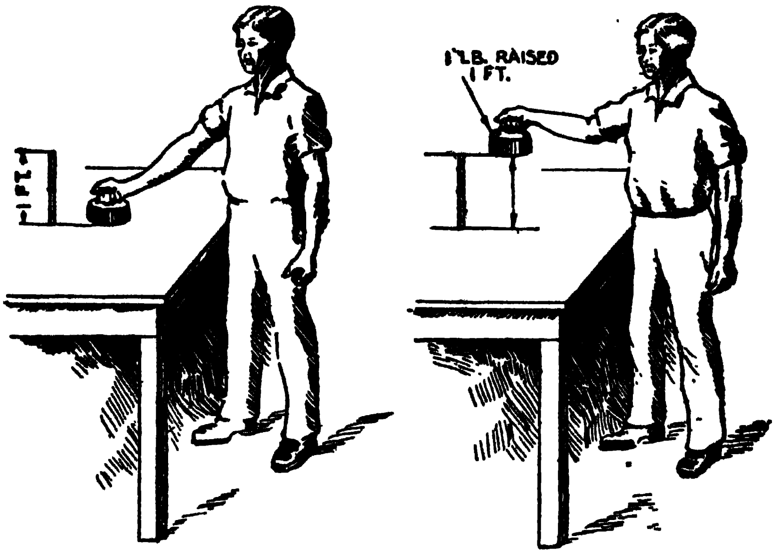
Ans. In foot pounds.

Ques. What is a foot pound?

Ans The amount of work done in raising a weight of one pound one foot or the equivalent, overcoming a pressure of one pound through a distance of one foot.

Ques. What is the electrical unit of work?

Ans. The *volt-coulomb.*



FIGS. 211 and 212.—One foot pound or unit of work defined as the work done in raising one pound one foot.

A volt-coulomb of work is performed when one ampere of current flows for one second in a circuit whose resistance is one ohm, when the pressure is one volt.

The Ampere-Hour.—A gallon of water may be drawn from a hydrant in a minute, or in an hour; it is still one gallon. So

in electricity, a given amount of the current, say one ***coulomb***, may be obtained in a second or in an hour.

The ampere is the unit rate of flow.

What is called the electric current is simply the relation of any quantity of electricity passed to the time it is passing; that is

quantity in coulombs = current in amperes × time in seconds,
or simply

$$\text{coulomb} = \text{ampere} \times \text{second}.$$

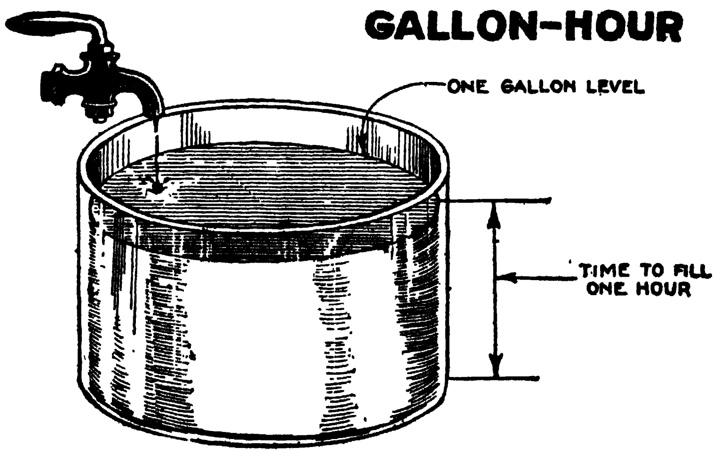


FIG. 213.—Hydraulic analogy of ampere hour. ***Imagine*** water flowing into the vessel at the rate of one gallon in one hour; this is one gallon-hour. ***Similarly*** if in an electric circuit the current flow at the rate of one ampere, that is, one coulomb per second for one hour, this is one ampere hour.

Again·

$$\begin{aligned} 10 \text{ coulombs} &= 1 \text{ ampere} \times 10 \text{ seconds} \\ &= 2 \text{ amperes} \times 5 \text{ seconds} \\ &= 10 \text{ amperes} \times 1 \text{ second, etc.} \end{aligned}$$

One *ampere hour* is simply another way of saying 3,600 coulombs. Of course 3,600 coulombs of electricity may be

obtained in any desired time. It all depends on the rate of flow or the current strength in amperes.

For instance, 2 amperes in ½ hour, or 4 amperes in ¼ hour will also give one ampere-hour of 3,600 coulombs.

It is well to keep the distinction between coulombs and amperes in mind.

To illustrate further the difference between coulombs and amperes, the following example is given.

It is sometimes estimated that the quantity of electricity in a flash of lightning is $\frac{1}{10}$ coulomb, and the duration of the discharge $\frac{1}{20,000}$ part of a second. What is the current in amperes?
Now since

$$\text{coulombs} = \text{amperes} \times \text{seconds} \qquad (1)$$

solving (1) for the current,

$$\text{amperes} = \frac{\text{coulombs}}{\text{seconds}} \qquad (2)$$

substituting the given values in (2),

$$\text{amperes} = \frac{\frac{1}{10}}{\frac{1}{20,000}} = 2,000$$

Power.—The term power means *the rate at which work is done;* it is usually expressed as *the number of foot pounds done in one minute,* that is

$$\text{power} = \frac{\text{foot pounds}}{\text{minutes}}$$

Power exerted for a certain time produces work.

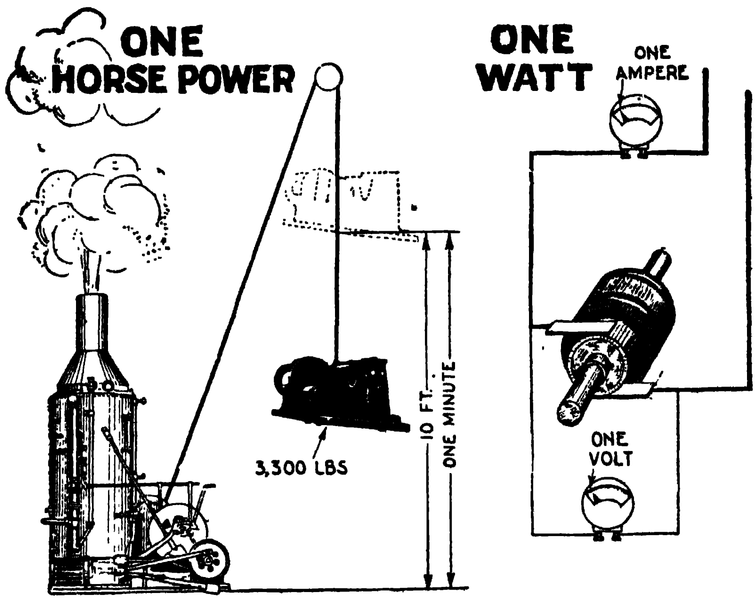
Ques. What is the mechanical unit of power?

Ans The horse power.

Ques. What is one horse power?

Ans. 33,000 foot pounds per minute.

The unit is due to James Watt as being the power of a strong London draught horse to do work during a short interval and used by him to measure the power of his steam engines. One horse power = 33,000 ft. lbs. per minute = 550 ft. lbs. per sec. = 1,980,000 ft. lbs. per hour.



FIGS 214 and 215.—Examples illustrating one horse power and one watt. ***Rules:*** One horse power = 33,000 ft. lbs. per minute. One watt = one ampere × one volt.

Ques. What is one horse power hour?

Ans. Work done at the rate of one horse power for one hour.

Ques. What is the electrical unit of power?

Ans. The watt.

Ques. What is a watt?

Ans. It is the power due to a current of one ampere flowing at a pressure of one volt. One watt = one ampere × one volt. It is equal to one joule per second.

Ques. What is a kilowatt?

Ans. 1,000 watts.

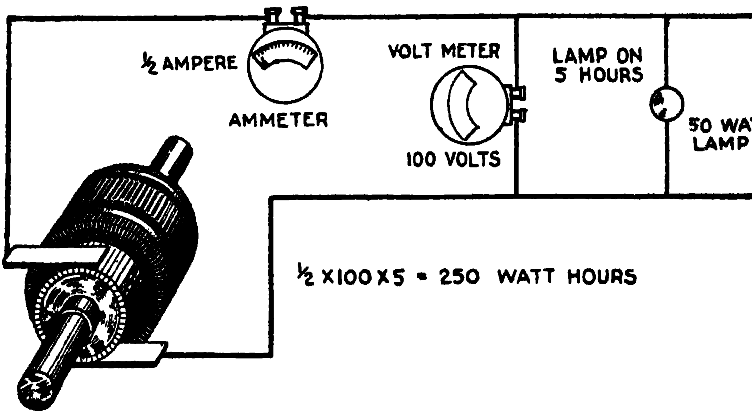


FIG. 216.—Example illustrating watt hours. Rule: Watt hours = amperes × volts × hours.

The Watt Hour.—The elements which may be measured are, however, not only the volume of current, the unit of which is the ampere, and time, the unit of which is the hour, but also the *pressure*, the unit of which is the volt.

It is evident that a perfect system of electrical measurements should take account of the total amount of energy consumed, and should depend not only upon the volume of current, but *also upon the pressure* at which the current is applied.

The basis of such a system if provided in a unit which is the product of the two units of current and pressure, and which is termed a *volt ampere* or *watt*.

The watt hour represents the amount of work done by an electric current of one ampere strength flowing for one hour under a pressure of one volt.

Example.—An incandescent lamp taking one-half an ampere of current on a circuit having a pressure of 100 volts, or a lamp taking one

FIG. 217.—Method of judging the heat of a soldering bit or so called "iron," illustrating *sensible heat*.

ampere on a circuit having a pressure of 50 volts, would each be consuming 50 watts of energy, and this multiplied by the number of hours would give the total number of watt hours for any definite time.

The watt, then, is an accurate and complete unit of measurement and is generally applicable to all forms of electrical consumption.

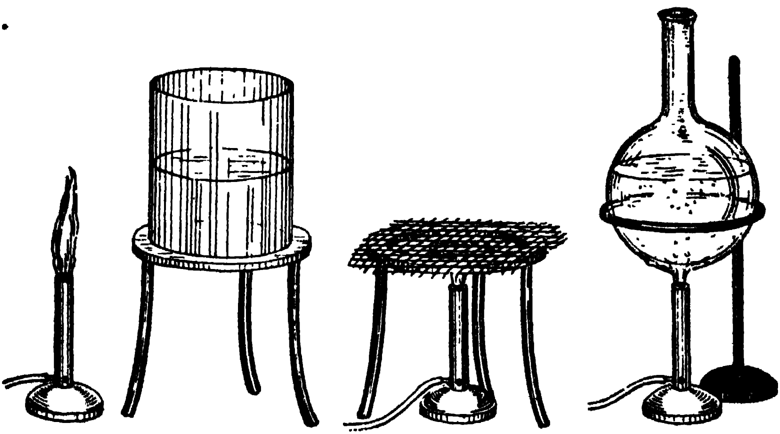
A watt of electrical energy corresponds to $\frac{1}{746}$ of a horse power of

mechanical energy; hence, if a lamp or motor require energy equivalent to $\frac{1}{746}$ of a horse power for one hour, it might be said to take one watt-hour.

Heat.—By definition, ***heat is a form of energy.*** Heat is produced in the agitation of the molecules of matter—the energy expended in agitating these molecules is transformed into heat.

Heat is measured in *calories* or British thermal units (abbreviated *B.t.u.*).

A calorie is the ***amount of heat necessary to raise the temperature of one gram of water from*** 0° ***to*** 1° ***Centigrade;*** sometimes called the ***smaller calorie*** or ***therm.***



FIGS. 218 to 220 —Three ways in which heat is transferred; fig. 218, by radiation; fig. 219, by conduction; fig. 220, by convection. In fig. 218, the water in the beaker is heated by *heat rays which radiate in straight lines in all directions from the flame.* In fig. 219, the flame will not pass through the wire gauze, because the latter conducts the heat away from the flame so rapidly that the gas on the other side is not raised to the temperature of ignition. In fig. 220, the water nearest the flame becomes heated and expanded. It is then rendered less dense than the surrounding water, and hence rises to the top while the colder and therefore denser water from the sides flows to the bottom thus *transferring heat by convection currents.*

A British thermal unit (*B.t.u.*) is $\frac{1}{180}$ of the heat required to raise 1 lb. of water from 32° to 212° Fahr. (*Marks and Davis.*)

The calorie is used for calculation in Physics and the British thermal unit for commercial calculation.

Heat is produced in the agitation of the molecules of matter; the energy expended in agitating these molecules is transformed into heat.

Mechanical Equivalent of Heat.—The eminent English physicist, James Prescott Joule, worked for more than forty years in establishing the relation between *heat* and *mechanical work;* he stated the doctrine of the conservation of energy and discovered the law, known as Joule's law, for determining the relation between the heat, current pressure, and time in an electric circuit.

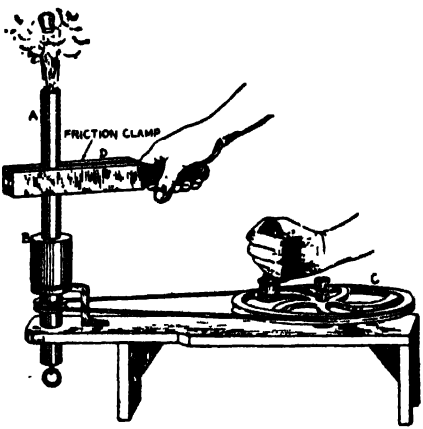
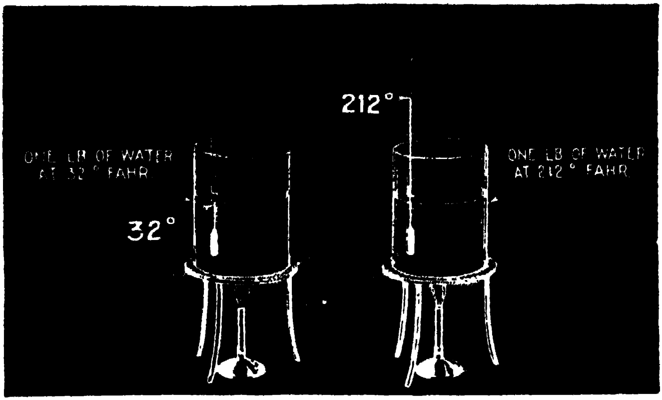


FIG. 221.—Experiment showing relation between heat and work. Take a brass tube AB, attached to a spindle geared to rotate rapidly and partly fill the tube with water and insert a cork. Apply a friction clamp D, and rapidly rotate the tube by turning the wheel C. The energy expended in overcoming the friction due to the clamp and rotating the tube causes the water to heat and finally boil; if continued long enough, the pressure generated will expel the cork. During the operation *work has been transformed into heat.*

Ques. What is the mechanical equivalent of heat?

Ans. The number of foot pounds of mechanical energy equivalent to one British thermal unit.



FIGS. 222 and 223.—Experiment illustrating the British thermal unit. Place one pound of water at 32° Fahr. into a beaker over a Bunsen burner as in fig. 222 assuming no loss of heat from the water. It will, according to the definition, require 180 heat units to heat the water from 32° to 212° Fahr. Now, if the transfer of heat take place at a uniform rate and it require, say five minutes to heat the water to 212°, then one heat unit will be transferred to the water in $(5 \times 60) \div 180 = 2$ seconds.

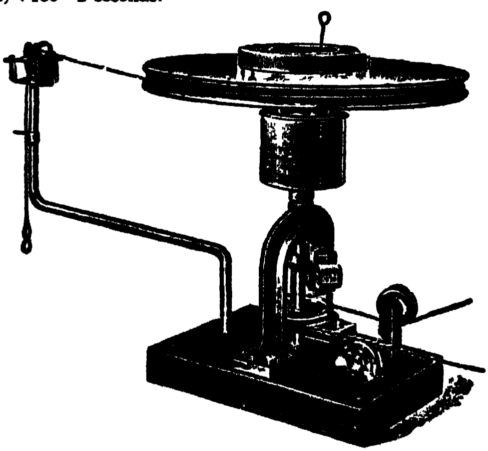


FIG. 224.—Callendar's mechanical equivalent of heat apparatus (Central Scientific Co.). With this apparatus a lecturer can obtain in about ten minutes in the presence of a class of students, a value of "J" correct to ⅕ per cent. Joules experiments 1843-50, gave the figure 772, known as "Joules equivalent," more recent experiment by Prof. Rowland (1880) and others give higher figures: 778 is generally accepted. Marks and Davis value is 777.54 ft. lbs.

Joule's experiments 1843–50 gave the figure 772 ft. lbs. which is known as Joule's equivalent. Later experiments gave higher figures, and *the present accepted value is 778 ft. lbs.*, that is: 1 *B.t.u.* = 778 ft. lbs.

Electrical Horse Power.—It is desirable to establish the relation between *watts* and *foot pounds* in order to determine the *capacity* of a dynamo or motor in terms of *horse power.*

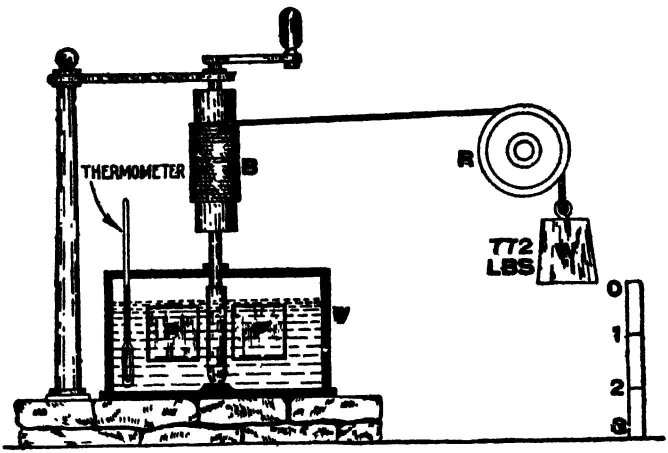


FIG. 225.—The mechanical equivalent of heat. In 1843, Dr. Joule of Manchester, England, performed his classic experiment, which revealed to the world the mechanical equivalent of heat. As shown in the figure, a paddle was made to revolve with as little friction as possible in a vessel containing a pound of water whose temperature was known. The paddle was actuated by a known weight falling through a known distance. *A pound falling through a distance of 1 ft represents a ft. lb. of work.* At the beginning of the experiment a thermometer was placed in the water, and the temperature noted. The paddle was made to revolve by the falling weight. When 772 ft. lbs. of energy had been expended on the pound of water, the temperature of the latter had risen one degree, and the relationship between heat and mechanical work was found; the value 772 ft. lbs. is known as Joule's equivalent. More recent experiments give higher figures, the value 778, is now generally used but according to Kent 777.62 is probably more nearly correct. Marks and Davis in their steam tables have used the figure 777.52.

One watt is equivalent to one joule per second or 60 joules per minute. One joule in turn, is equivalent to .7374 ft. lbs., hence 60 joules equal:

$$60 \times .7374 = 44.244 \text{ ft. lbs.}$$

Since one horse power = 33,000 ft. lbs. per minute, the electrical equivalent of one horse power is

$$33{,}000 \div 44.244 = 746 \text{ watts.}$$

or,

$$\frac{746}{1{,}000} = .746 \text{ kilowatt } (kw.)$$

Again, one kilowatt or 1,000 watts is equivalent to

$$1{,}000 \div 746 = 1.34 \text{ horse power}$$

The Farad.—The measure constructed to hold a gallon of water may be called the gallon measure.

The capacity of a condenser which would contain a charge of one coulomb under one volt pressure is the farad.

It may seem strange that there is a unit of quantity and another of capacity to hold that quantity, when in the case of water the term "gallon" may suffice for the measure and the liquid it can hold. Electricity in this respect, however, corresponds to a *compressible fluid* or a *gas*.

A gallon measure may hold a gallon of gas or ten; it depends entirely upon the pressure. Accordingly a condenser of a certain size may hold any number of coulombs, according to the electrical pressure.

The farad being inconveniently large for practical use, one-millionth of a farad, called a *microfarad*, is generally adopted.

*NOTE.—*James Watt* was early asked by would-be purchasers as to how many horses his engines would replace. To obtain data as to actual performance in *continuous* work, he experimented with powerful brewery horses, and found that one traveling at 2½ miles per hour, or 220 feet per minute, and harnessed to a rope leading over a pulley and down a vertical shaft, could haul up a weight averaging 100 lbs., equaling 22,000 foot pounds per minute. To give good measure, Watt increased the measurement by 50 per cent., thus getting the familiar unit of 33.000 *foot pounds* per minute.

TEST QUESTIONS

1. *What is energy?*
2. *What is the difference between potential and kinetic energy?*
3. *What is matter?*
4. *What is the difference between an atom and a molecule, and how do they behave?*
5. *What is the difference between electricity and magnetism?*
6. *What is work and how is it measured?*
7. *What is a foot pound?*
8. *When is a volt-coulomb of work performed?*
9. *Give hydraulic analogy of ampere hour.*
10. *Give a distinction between coulombs and amperes.*
11. *Define power, and what does work exerted for a certain time produce?*
12. *Define one horse power.*
13. *What is a watt?*
14. *Explain the term watt hour.*
15. *What is the mechanical equivalent of heat and what is heat; how is it measured?*
16. *Define the British thermal unit.*
17. *What is the difference between mechanical and electrical horse power?*
18. *What is a farad; give hydraulic analogy.*
19. *How is heat produced; how measured?*
20. *What is the difference between a British thermal unit and a calorie?*

CHAPTER 8

Effects of the Current

The term "electric current," in the present state of our knowledge, should be regarded as denoting the existence of a state of things in which certain definite experimental effects are produced, for some of which there certainly is no analogy exhibited in ordinary hydraulic currents. The following are the most important of these effects:

1. Thermal effect;
2. Magnetic effect;
3. Chemical effect.

It is rather to these effects than to any imaginary current flow in the conductor that the attention of the reader should be directed.

With this preliminary caution, which should never be lost sight of, the use of familiar words and expressions connected with the flow of water in pipes is justified in order to avoid roundabout and cumbrous phrases which, though perhaps more nearly in accord with present knowledge of the facts, would not tend to clearness or conciseness.

The three most important effects of the current just mentioned, may be presented in more detail as follows:

1. The *Thermal effect*.

The conductor along which the current flows becomes heated. The rise of temperature may be small or great according to circumstances, but some heat is always produced.

2. The *Magnetic effect.*

The space both outside and inside the substance of the conductor, but more especially the former, becomes a "magnetic field" in which delicately pivoted or suspended magnetic needles will take up definite positions and magnetic materials will become magnetized.

3. The *Chemical effect.*

If the conductor be a liquid which is a chemical compound of a certain class called *electrolyte*, the liquid will be decomposed at the places where the current enters and leaves it.

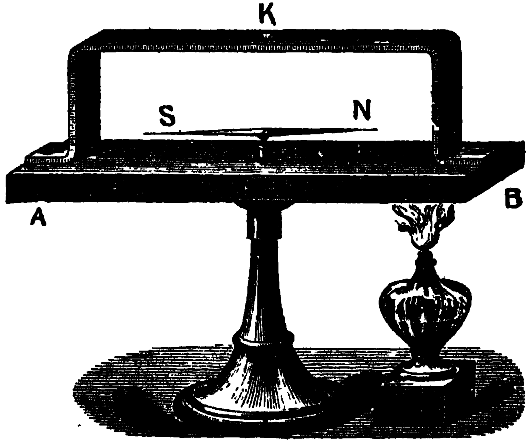


FIG. 226.—The Seebeck effect: *If in a complete metallic circuit having junctions of dissimilar metals, the junctions are at different temperatures, then generally a steady current will flow in the circuit as long as the differences of the temperatures of the junction is maintained.* To demonstrate this, a piece of copper K, bent in the shape seen in the figure, was placed on a block of bismuth AB, carrying a pivoted magnetic needle NS; as soon as the equality of temperatures was altered by either heating or cooling one of the junctions of the two metals, the needle indicated a current which continued to flow as long as the difference of temperature was maintained at the junctions. The movement of the needle indicated the direction in which the current flowed. If, for instance, the north junction B, were heated, the N, pole moved eastward, showing that at the heated junction the current flows from the bismuth to the copper, at the cold junction from the copper to the bismuth.

Thermal Effect.—If a quantity of electricity were set flowing

in a closed circuit and the latter offered no *resistance*, it would flow forever, just as a wagon set rolling along a circular railway would never stop *if there were no friction*.

When matter in motion is stopped by friction, the energy of its motion is converted into heat by the friction thus causing the matter to come to rest. Similarly, *when electricity in motion, that is, an electric current is stopped by* ***resistance***, *the energy of its flow is transformed into* ***heat*** *by the resistance of the circuit.*

If the terminals of a battery be joined by a short thick wire of low resistance, most of the heat will be developed in the battery, whereas, if a thin wire of high resistance be used it will become hot, while the battery itself will remain comparatively cool.

To investigate the development of heat by a current, Joule and Lenz used instruments on the principle of fig. 227, in which a thin wire joined to two stout conductors is enclosed within a glass vessel containing alcohol, into which is placed a thermometer. The resistance of the wire being known, its relation to the other resistances can be calculated.

Joule found that the number of heat units developed in a conductor is proportional to:

1. The resistance;
2. The square of the current strength;
3. The time that the current lasts.

Joules' law may be stated as follows:

The ***heat*** *generated in a conductor by an electric current is proportional to the resistance of the conductor, the time during which the current flows, and the square of the strength of the current.*

The quantity of heat in calories may be calculated by use of the equation,

$$\text{calories per second} = \text{volts} \times \text{ampere} \times .24. \tag{1}$$

The total number of calories or heat developed in seconds will be given by

$$\text{heat} = \text{volts} \times \text{amperes} \times \text{seconds} \times .24. \qquad (2)$$

Example.—If a current of 10 amperes flow in a wire whose terminals are at a pressure difference of 12 volts, how much heat will be developed in 5 minutes?

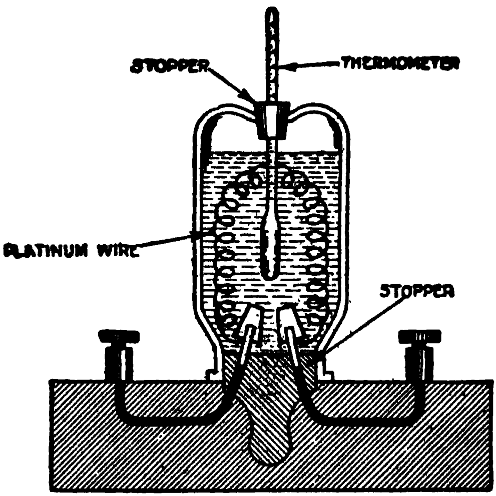


FIG. 227.—Lenz's apparatus for measuring the heat given off by an electric current. It consisted of a wide mouthed stoppered bottle fixed upside down, with its stopper, in a wooden box; the stopper was perforated so as to give passage to two thick platinum wires, connected at one end with binding screws, while their free ends were provided with platinum cones by which the wires under investigation could be readily affixed; the vessel contained alcohol, the temperature of which was indicated by a thermometer fitted in a cork inserted in a hole made in the bottom of the vessel. The current is passed through the platinum wires, and its strength measured by means of a galvanometer interposed in the circuit. By observing the increase of temperature in the thermometer in a given time and knowing the weight of the alcohol, the mass of the wire, the specific heat, and the calorimetric values of the vessel, and of the thermometer, compared with alcohol, the heating effect which is produced by the current in a given time can be calculated.

Substituting in equation (2):

$$10 \times 12 \times (60 \times 5) \times .24 = 8640 \text{ calories.}$$

Since by Ohm's law, the pressure difference or

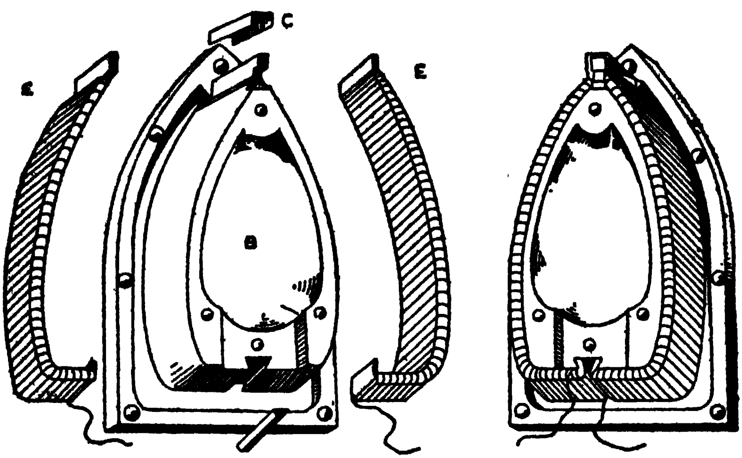
$$\text{volts} = \text{amperes} \times \text{ohms}$$

Substituting in equation (2):

$$\text{heat} = \text{amperes}^2 \times \text{ohms} \times \text{seconds} \times .24. \qquad .(3)$$

Use of Heat from Electric Current.—In the transmission of electricity from place to place, it is very desirable that none of the energy be expended in heating the conductor. Hence copper wires of the proper size must be used.

In wiring a building for electric lights, the insurance rules



FIGS. 228 to 231.—Details of construction of electric iron. Figs. 228 and 230, heating elements; fig. 230, iron base; fig. 231, assembly.

require that the wires be of a certain size and that they be put up in a certain manner. Otherwise they will not insure a building against fire.

It is often desirable, however, to use the electric current for the purpose of producing heat. The carbons of the arc and incandescent lamps are intensely heated that they may produce light.

Coils of German silver wire or other high resistance wire are heated by the passage of a current through them. In this manner the electric stove is made.

Soldering coppers, smoothing irons, and baking ovens are heated in a similar manner.

Magnetic Effect.—An electric current flowing in a wire causes

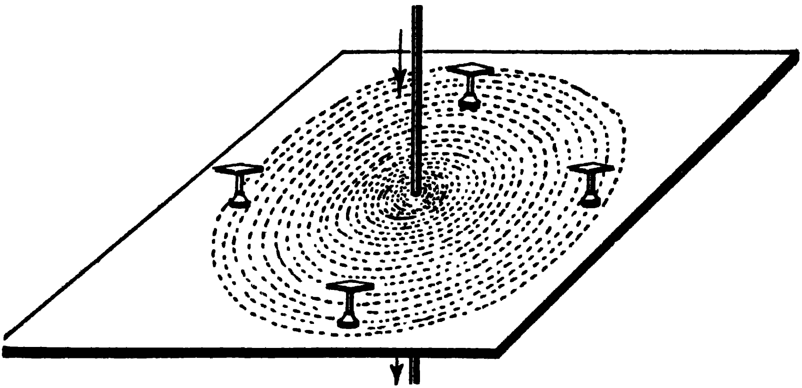
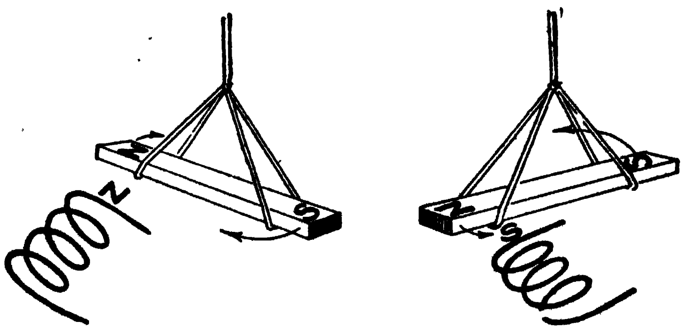
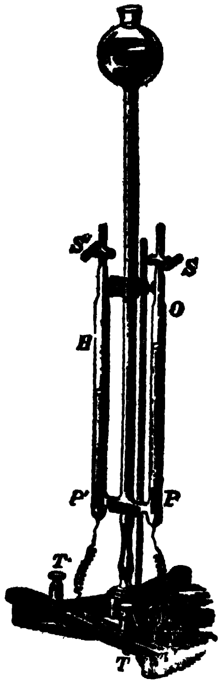


FIG. 232.—Magnetic field surrounding a wire in which a current is flowing. The magnetic field consists of lines of force which are circles concentric with the wire as indicated by a compass which will point in a direction perpendicular to the radius joining the compass and



FIGS. 233 and 234.—Mechanical effect of the current: *Like poles repel each other; unlike poles attract each other.*



it to be surrounded by a *magnetic field*, which consists of *lines of force* encircling the wire. The field is strongest near the wire and diminishes gradually in strength at increasing distances therefrom. The presence of this magnetic field is shown by various experiments and the subject is fully explained in Chapter 9 on *magnetism*.

Chemical Effect.—Pats van Trostwyk (1789) pointed out that *an electric discharge was capable of decomposing water*.

To show this he used gold wires, which he allowed to dip in water, connecting one of them with the inner, and another with the outer coating of a Leyden jar, and passing the discharge through the water. The gas bubbles collected proved to consist of oxygen and hydrogen gas.

Nicholson and Carlisle (1800) dipped a copper wire which was connected with one of the poles of a voltaic pile into a drop of water, which happened to be on the plate

FIG. 235.—Modern apparatus for decomposing water by electrolysis. Platinum electrodes *P* and *P'*, are placed at the bottom of two upright tubes *O* and *H*, and are connected to the terminals *T* and *T'*, by platinum wires, which are fused through the glass of the tubes. These tubes have glass stop cocks *S* and *S'*, at their upper ends, and at their lower ends are connected by a short glass tube, from the center of which rises the large central tube which expands with a bulb at its upper end, which is open at the top. The three tubes can be filled with acidulated water from the central tube, the previously contained air being allowed to escape through the stop cocks, which are afterwards closed. If it be so filled, and the terminal *T*, be attached to the positive and *T'*, to the negative pole of a suitable battery, bubbles of gas will be observed to rise from the plates *P* and *P'*, and finding their way to the top of the respective tubes, will displace the liquid, which will be driven into the open central tube. The gas rising from the anode *P*, is oxygen (O), and that rising from the cathode *P'*, is hydrogen (H). If the tubes be graduated, the latter will be found to occupy about twice the volume of the former. The proportion is theoretically 2 to 1; however, on account of the different solubilities of the two gases in water, oxygen bring the more soluble of the two, is deficient in quantity.

connected with the other pole; gas bubbles appeared, and the drop of water became smaller and smaller.

This experiment was repeated in a somewhat different manner, the brass wires from a pile being brought under a tube filled with water and closed at the top. Gas bubbles were produced by the wire in connection with the negative pole of the pile, and the water was observed to diminish gradually. At the positive wire, on the contrary, no gas came off, but the metal lost its metallic lustre, became dark, and finally crumbled away. The gas which had collected in the tube proved to be hydrogen; while on examining the black mass it was found that the constituents of brass, viz., copper and zinc, had become oxidized.

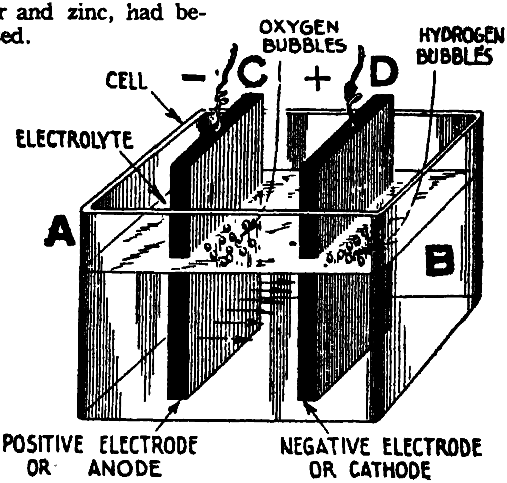


FIG. 236.—An electrolytic cell. The parts are: A, cell; B, electrolyte; C, positive electrode or anode; D, negative electrode or cathode.*

Electrolysis.—*Electric analysis* or more briefly *electrolysis* was the term applied by Faraday to the process of decomposing a liquid by the passage of a current of electricity through it.

The vessel containing the liquid is known as an *electrolytic cell*. In fig. 236, A, is the cell, which may be of glass or of any

*NOTE.—*The cathode* is the conductor by which current flows away as distinguished from the *anode* or conductor through which the current enters. The terms usually apply to to conductors leading the current through a liquid or gas, as an electrolytic cell, or vacuum tube.

other suitable material, and B, is the liquid which is to be electrolyzed. Current enters by the *positive electrode* C, also known as the *anode*, traverses the liquid, and leaves by the *negative electrode*, or *cathode* D.

The passage of current through the water splits up its molecules into their constituent atoms of oxygen and hydrogen, the former being given off in bubbles at the anode, and the latter at the cathode.

When current is passed through a solution of copper sulphate between platinum electrodes, the liquid is decomposed, atoms of copper being deposited at the cathode, bubbles of oxygen being given off at the anode, and sulphuric acid being formed in the liquid, which latter becomes more and more acid as the copper is withdrawn.

If, however, the anode be of copper instead of platinum, no sulphuric acid will be formed, neither will oxygen be given off at the anode. As copper is deposited at the cathode, an equal quantity will be dissolved at the anode, so that the original constitution of the liquid is maintained.

The atoms separated from each other by the electric current were called **ions** *by Faraday; those going to the anode being* **anions**, *and those going to the cathode being* **kathions**.

Anions are generally regarded as *electro-negative*, because they move as if attracted to the positive electrode, while kathions are regarded as *electro-positive*.

In order to explain the transfer of electricity and the transfer of matter through the electrolyte, Grotthuss put forward the hypothesis that *when two metal plates at different pressures are placed in a cell, the effect produced in the liquid is that the molecules of the liquid arrange themselves in innumerable chains*, as shown in fig. 237, *in which every molecule has its atoms pointing in a certain direction, the electro-positive atom being attracted*

toward the cathode and the electro-negative toward the anode. An interchange then takes place all along the line, the free atoms appearing at the electrodes, and every atom discharging a minute charge of electricity upon the electrode at which it is liberated.

Grotthuss' Theory (announced in 1806). *The molecules in an electrolyte have their individual electro-positive and electro-negative atoms charged positively and negatively respectively.*

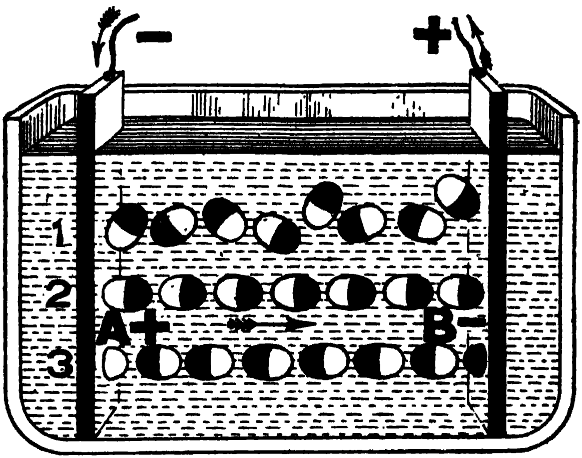


FIG. 237.—Grotthuss' theory of electrolysis. Grotthuss (in 1806), announced his theory that *the molecules in an electrolyte have their individual electro-positive and electro-negative atoms charged positively and negatively respectively.* In an ordinary liquid, for instance in water, the molecules are arranged indifferently, like row 1, with their positive and negative ends pointing in all directions. When the charged plates A and B, connected to the − and + poles of a battery, are inserted in the water, the molecules under the action of the laws of electrostatic action turn as shown in row 2, so that all the hydrogen or shaded ends (+) are turned toward the (−) plate B, and all the oxygen or unshaded ends (−) toward the (+) plate A. All along the row, the electrical forces are supposed to tear the molecules asunder, depositing H on B, and O on A. The atoms in the middle of the liquid, however, recombine, for the hydrogen atoms in their journey toward B, meet the oxygen atoms travelling in the opposite direction, and the state of affairs represented in row 3 obtains. The next step is to rotate once more the atoms into the positions shown in row 2, and so on. In this way the theory accounts for the products only appearing at the electrodes and not in the body of the liquid.

Electro-chemical Series.—This is *an arrangement of the metals in a series in such a manner that the most electro-positive is at one end and the most electro-negative at the other.*

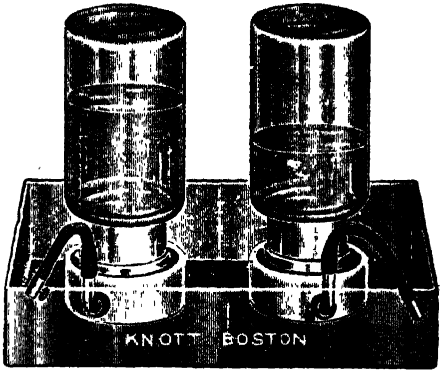


Fig. 238.—Packard electrolysis apparatus designed by J. C. Packard of Brookline High School. ***It consists of*** two special molded porcelain bottle rests which are designed as electrode supports. These bottle and electrode supports can be used close together or apart to the limit of the glass tray. ***In use,*** the bottles and tray are filled with the electrolyte to a point covering the mouths. When current is connected, action immediately begins.

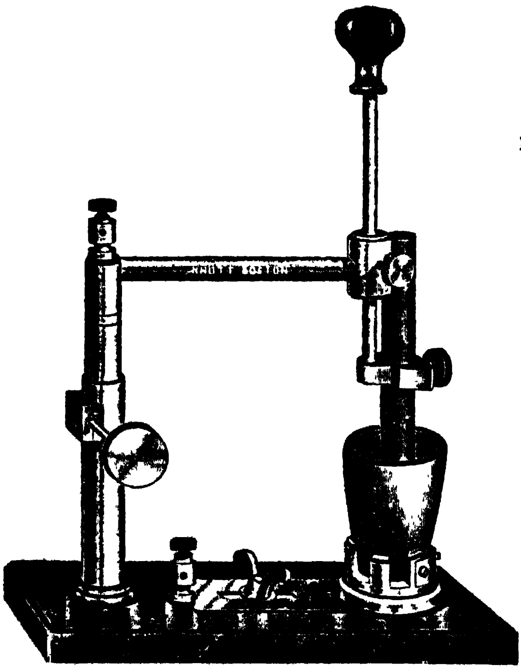


Fig. 239.—**Knott simple electric furnace for explaining the electric arc, electric furnace, as well as the melting and combining properties of many elements. The construction enables a clear understanding of the many principles involved. Its open construction has great pedagogic value. A great variety of experiments can be conveniently performed—the melting of platinum or like refractory metals, the reduction or production of aluminum or carbides. The manufacture of calcium carbide from lime and sawdust or carbon makes a striking and interesting experiment.**

The order of the metals varies with the electrolyte in which the metals are tested.

The following table shows such series for the most common metals, in three different solutions:

Sulphuric acid	*Hydrochloric acid*	*Caustic potash*
Zinc	Zinc	Zinc
Cadmium	Cadmium	Tin
Tin	Tin	Cadmium
Lead	Lead	Antimony
Iron	Iron	Lead
Nickel	Copper	Bismuth
Bismuth	Bismuth	Iron
Antimony	Nickel	Copper
Copper	Silver	Nickel
Silver	Antimony	Silver
Gold		
Platinum		

Faraday stated several laws of electrolysis as follows:

Law 1.—The quantity of an ion liberated in a given time is proportional to the quantity of electricity that has passed through the voltameter in that time.*

Law 2.—The quantity of an ion liberated in a voltameter is proportional to the electro-chemical equivalent of the ion.

Law 3.—The quantity of an ion liberated is equal to the electro-chemical equivalent of the ion multiplied by the total quantity of electricity that has passed.

Electric Osmose.—Porret observed that if a strong current be led into certain liquids as if to electrolyze them, a porous partition being placed between the electrodes, the current mechanically carries part of the liquid through the porous diaphragm, so that the liquid is forced to a higher level on one side than on the other. This phenomenon is known as *electric osmose.*

Voltameter.—The name *voltameter* was given by Faraday to an electrolytic cell employed as a means of measuring an electric current by the amount of chemical decomposition the current effects in passing through the cell.

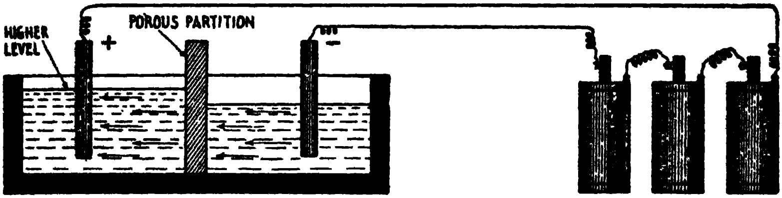


FIG. 240.—Electrolytic cell with porous partition illustrating *electric osmose*. Porret observed that if a strong current be led into certain liquids, a porous partition being placed between the electrodes, the liquid is carried by the current through the porous partition, until it is forced up to a higher level on one side than on the other. This electric action is most pronounced when the experiment is made with liquids, which are poor conductors. The movement of the liquid takes place in the direction of the current.

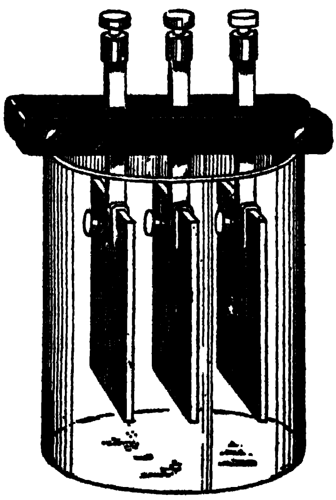


FIG. 241.—Copper voltameter (coulomb meter). It has two loss plates and one gain plate. Note that the construction of the clamping device is such that the plates may be handled without touching them with the fingers.

Gernez has recently shown that in a bent closed tube, containing two portions of liquid, one of which is made highly + and the other highly −, the liquid passes over from + to − This apparent distillation is not due to difference of temperature, nor does it depend on the extent of surface exposed, but is effected by a slow creeping of the liquid along the interior surface of the glass tubes. Bad conductors, such as turpentine, do not thus pass over.

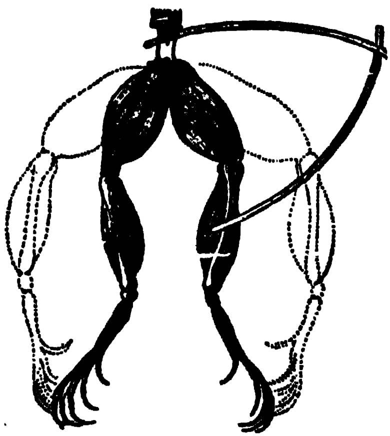


FIG. 242.—Effect of the electric current on a frog's legs; discovered in 1678 by Galvani.

Muscular Contractions.—It was discovered in 1678 that *when a portion of muscle of a frog's leg, hanging by a thread of nerve bound with a silver wire, was held over a copper support so that both nerve and wire touched the copper, the muscle immediately contracted.*

More than a century later Galvani's attention was drawn to the subject by his observation of spasmodic contractions in the legs of freshly

killed frogs under the influence of the "return shock" experienced every time a neighboring electric machine was discharged.

The limbs of the frog, prepared as directed by Galvani, are shown in fig. 242. After the animal has been killed the hind limbs are detached and skinned; the crural nerves and their attachments to the lumbar vertebræ remaining. For some hours after death the limbs retain their contractile power. The frog's limbs thus prepared form an excessively delicate galvanoscope.

Electroplating.—This is the process *of depositing a layer or*

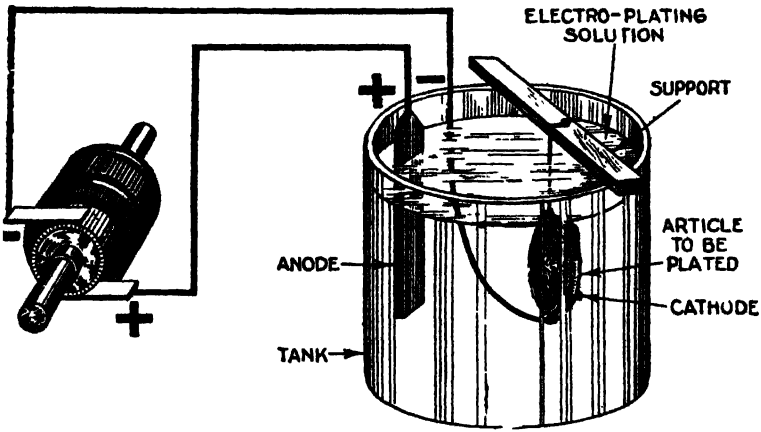


FIG. 243.—Example of electroplating showing essentials of the process.

coating of a rarer metal upon the surface of a baser, or of a metal upon any conducting surface, by electrolysis.

The electric current used may be obtained from a battery or other source. The battery has its positive plate connected to a rod extending across a trough or tank containing the plating bath.

Suspended from the rod are anodes of gold, silver, or copper or whatever metal from which a deposit is desired. The other plates of the battery or the negative elements, are connected with another rod across the trough, to which are suspended the articles to be plated.

Electrotyping.—This is the process by which, type, wood cuts, etc., are reproduced in copper by the process of electroplating.

A mould is first made of the set type in wax; this mould is next coated with black lead to give it a metallic surface, as the wax is an insulator; the mould is then subjected to the process of electrodeposition, resulting in the formation of a film of copper on the prepared surface.

Describing the process in detail, fill a case with a wax composition to a proper thickness. Then the surface of the wax case should be brushed over with moulding-lead with a soft brush. The case is then placed with the wax face downward upon the form. To prevent the wax adhering to the type, the form is brushed over with black lead. The form with the wax case upon it is then placed in a hydraulic press and subjected to a steady pressure of about two tons to the sq. in.

After the mould is made, the high parts on the wax are cut down and the wide spaces are built up. The mould is next coated with black lead to give it a metallic surface. The wax being an insulator, the mould is then subjected to the process of electro-deposition, resulting in the formation of a film of copper on the prepared surface by forcing the air out of the mould with a force pump; then the surface is coated with a solution of sulphate of copper sprinkled with iron dust and thoroughly worked with a brush into all parts of the mould. The excess is then washed out with water.

A battery or dynamo is used to generate the current. The positive terminal of the source of current is connected to a rod extending across a trough or tank containing the plating bath. Suspended from the rod are anodes of copper, from which a deposit is desired. The other terminal of the source is connected with another rod across the trough, to which is suspended the mould to be plated forming the cathode.

The copper shell is removed from the wax mould by holding one corner of the shell and lifting it as the hot water is poured on it.

The shell is tinned by brushing the back with an acid solution; then covered with tin foil.

The shell is now laid in a backing pan, face down, and the pan placed on the hot metal in the furnace. The heat of the metal melts the tin foil and it adheres to the shell, then the backing pan is lifted out and placed on a stand.

The electrotype metal is now poured on the tinned shell very carefully until the proper thickness is reached.

The metal plate when cooled is cleaned and delivered to the finishing room.

Almost all the illustrations in this book, for example, are printed from electrotype copies, and not from the original wood blocks, which would not wear so well.

TEST QUESTIONS

1. *Explain the term electric current.*
2. *What are the three most important effects of the current?*
3. *What happens when an electric current is stopped by resistance?*
4. *Where is heat developed when the battery is short circuited?*
5. *What investigations were made by Joule and Lenz?*
6. *State Joule's law; give examples.*
7. *Why is copper desirable for conductors?*
8. *What kind of wire is used in electric heating devices?*
9. *Describe the magnetic effect of current.*
10. *Where is the field strongest?*
11. *Describe various experiments showing the presence of magnetic field.*
12. *What did Pats van Trostwyk point out?*
13. *Describe Nicholson and Carlisle experiments.*

14. *Define electrolysis; who originated the term.*
15. *Describe in detail the process of electrolysis.*
16. *What is the difference between an anode and cathode?*
17. *State Grotthuss' theory of electrolysis.*
18. *What is an electro-chemical series?*
19. *State Faraday's laws.*
20. *What did Porret observe?*
21. *Describe electric osmose in detail.*
22. *What is electric distillation?*
23. *What did Beccaria notice?*
24. *What is the difference between a volt meter and a voltameter?*
25. *What did Gernez show?*
26. *Describe Galvani's frogs' leg experiment.*

CHAPTER 9

Magnetism and Motors

Early experimenters dating back to the "dawn of history" applied the word "magnet" to certain hard black stones which possess the property of attracting small pieces of iron, and as discovered later, to have still the more remarkable property of pointing "North" and "South" when freely suspended on a piece of string. At this time the magnet received the name of *lodestone* or "leading stone."

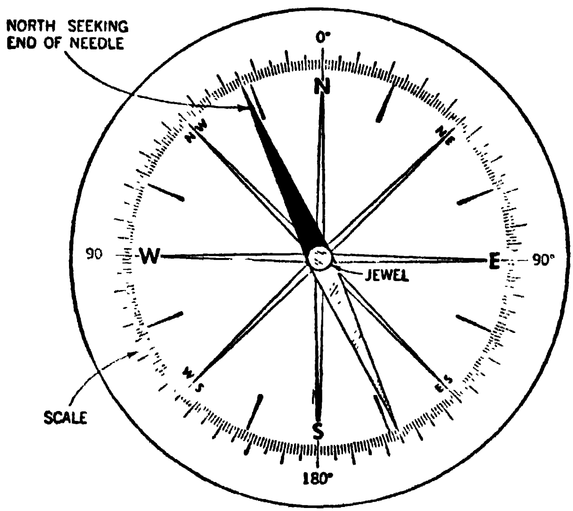


FIG. 1—Illustrating typical compass card. A compass consists essentially of a magnetic needle resting on a steel pivot, and protected by a brass case covered with glass and a graduated circle marked with the letters N,E,S and W, to indicate the cardinal points.

Kinds of Magnetism.—Magnets have two opposite kinds of magnetism or magnetic poles, which attract or repel each other in much the same way as the electrons generated by the rubbing of a stick of sealing wax with a piece of flannel, as described in an earlier chapter.

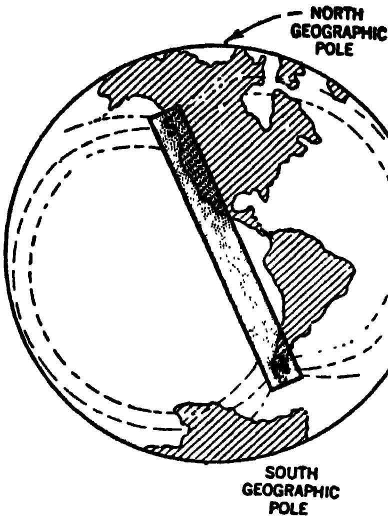


FIG. 2—Illustrating the magnetic properties of the earth. To comprehend the magnetic properties of the earth, the earth may be visualized as a gigantic sphere with its magnetic north and south poles being located several hundred miles distant from its geographic poles.

In our early school days, we learned that the earth is a huge, permanent magnet with its *North* magnetic pole somewhere in the Hudson Bay region and that the compass needle points toward the magnetic pole; that is, the point of the compass needle is a South Pole, magnetically speaking. The compass is thus an indication of magnetism.

One of the two spots on the magnet points North and the other South; they are called *poles;* one is called the *North-seeking* pole (*N*) and the other the *South-seeking* pole (*S*).

Experiments with Magnets.—If we bring the South-seeking or S-pole of a magnet near the *S-pole* of a suspended magnet, as in fig. 3, we find that the poles repel each other. If we bring

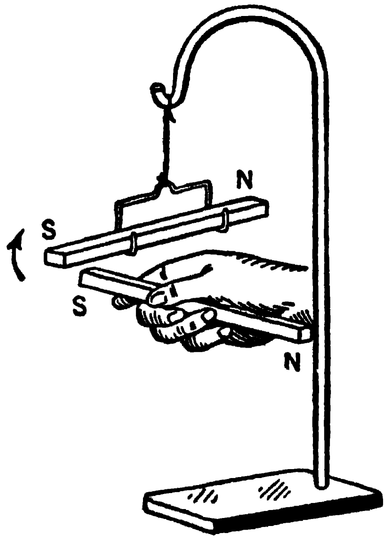


FIG. 3—Showing repulsion between like magnetic poles.

two *N-poles* together, they also repel each other, but if we bring an *N-pole* towards the *S-pole* of the moving magnet, or an *S-pole* toward the *N-pole*, they attract each other; that is, *like poles repel each other and unlike poles attract each other.*

It can also be shown by further experiments, that these attractive or repulsive forces between magnetic poles vary inversely as the square of the distance between the poles.

It will also be found that if a magnetic substance like iron filings be placed in a test tube and the latter stroked from end to end with a permanent magnet, that the filings themselves become a magnet. The acquired magnetism of the filings, however, will disappear as soon as the filings are shaken up.

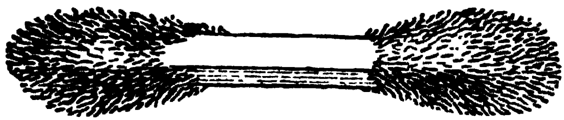


FIG. 4—Showing the effects of a magnet on iron filings. If a bar magnet be plunged into iron filings, and then lifted a mass of iron filings will adhere themselves to the ends of the magnet poles.

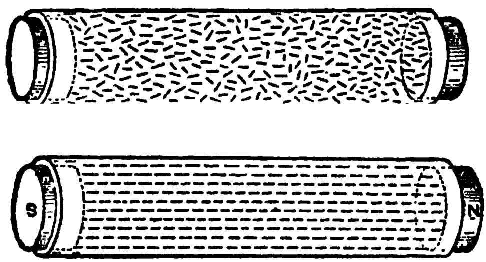


FIG. 5—Illustrating behavior of iron filings in a glass tube when tube be stroked with a permanent magnet. In this experiment it will be found that the iron filings which at first had no definite arrangement, will rearrange themselves under the influence of magnetic force, and assume symmetrical positions, each one lying in line with or parallel to its neighbor as shown in the lower figure.

For example, if a magnetized knitting needle is heated sufficiently it will be found to have lost its magnetism completely. Again, if such a needle be jarred, hammered or twisted, the strength of its poles as measured by their ability to pick up tacks or iron filings will be found to be greatly diminished.

Again, if a magnetized needle be broken, each part will be found to be a complete magnet, that is, two new poles will appear at the breakage point, a new *N-pole* on the part which has the original *S-pole*, and a new *S-pole* on the part which has the original *N-pole*. This subdivision of the needle may be continued indefinitely, but always with the same result as indicated in fig. 6. Thus it will be noted that no single magnetic pole can exist by itself, but will always appear as a North and a South pole, irrespective of the size involved.

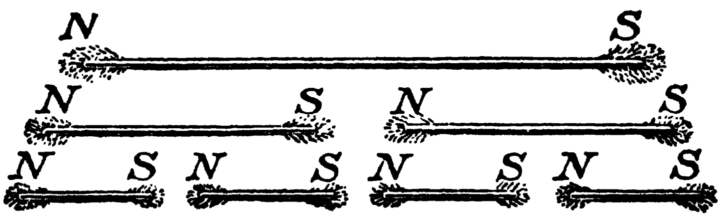


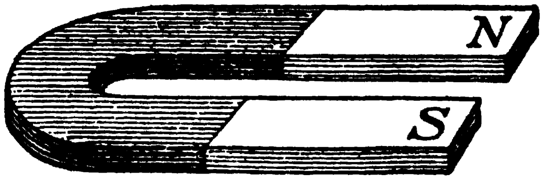
FIG. 6—Showing the effects of breaking a magnet into several parts. If a magnetized needle be broken, each part will be found to be a new magnet having an N and *S* pole. The sub-division may be continued indefinitely but always with the same result as indicated in the figure.

The foregoing facts also point to the conclusion that in any unmagnetized piece of iron, the atoms in it are not lined up in any particular order, that is, the electrons circling the nuclei of the iron atoms produce magnetic effects, but these effects cancel out each other.

On the other hand, when the iron is magnetized and becomes a magnet, the iron atoms are forced into a more definite alignment. Also the more strongly a piece of iron is magnetized, the more atoms are brought into alignment.

The fact that a piece of iron cannot be magnetized beyond a certain limit irrespective of the magnetizing force, is because

there is a definite limit to the number of atoms that can be made to stay in alignment, and when this limit is approached, the iron is said to be *fully magnetized* or *saturated*.



FIGS. 7 and 8—Showing a horseshoe magnet and bar magnet respectively.

Magnetic Materials.—Iron and steel are the only substances which exhibit magnetic properties to any marked degree. Nickel and cobalt are also attracted appreciably by strong magnets. Bismuth, antimony, and a number of other substances are actually repelled instead of attracted, but the effect is very small. For practical purposes *iron* and *steel* may be considered as the only magnetic materials.

The Magnetic Field.—It can easily be shown that when a straight bar magnet is held under a piece of cardboard upon which iron filings are sprinkled, the filings will arrange themselves in curved lines radiating from the poles.

If a horse shoe magnet be held at right angles to the plane of the cardboard the filings will arrange themselves in curved lines as shown in fig. 9. These lines are called *magnetic lines of force*

or simple *lines of force;* they show that the medium surrounding a magnet is in a state of stress, the space so affected is called the *magnetic field,* and the lines of force are collectively referred to as *magnetic flux.*

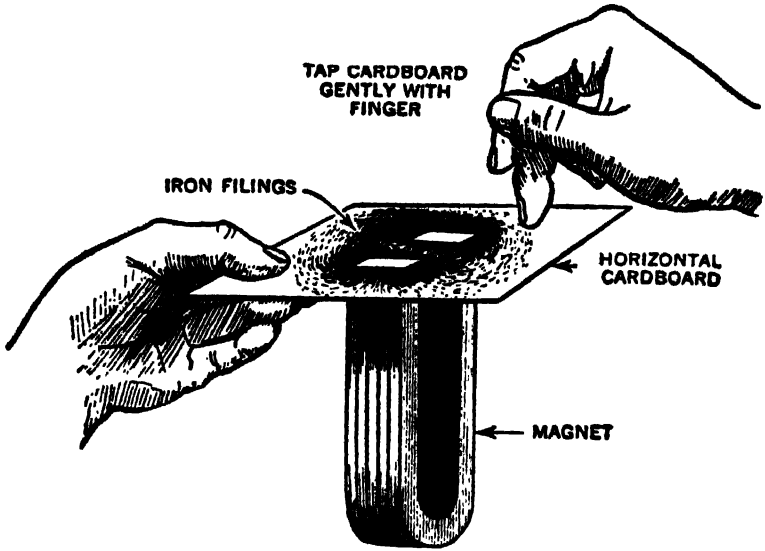


FIG. 9—Showing magnetic effect of a horseshoe magnet. The region about a magnet in which its magnetic forces can be detected is called the magnetic field. This can readily be presented graphically by placing a piece of cardboard over the magnet, sprinkling iron filings on the paper, gently tapping it at the same time. Each filing then becomes a temporary magnet by induction, and sets itself, like the compass needle, in the direction of the lines of force of the magnetic field.

Characteristics of the Magnetic Field.—The foregoing discussion of magnets and iron filings indicates certain characteristics common to all magnets, in that they produce *lines of force* and that these lines arrange themselves in certain geometrical patterns stretching from one pole to the other of the magnet.

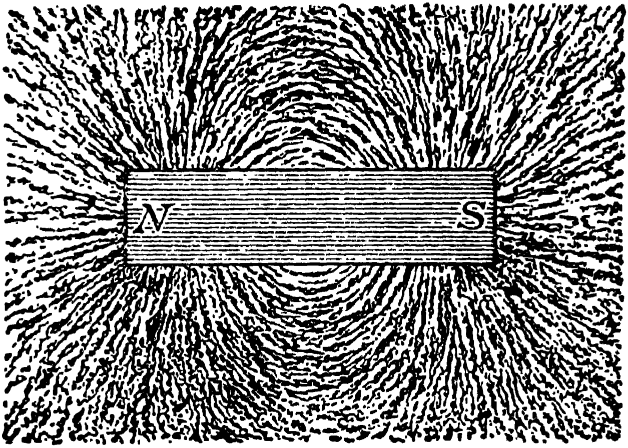


FIG. 10—Photographic illustration showing the magnetic lines of force as exerted by a bar magnet on iron filings.

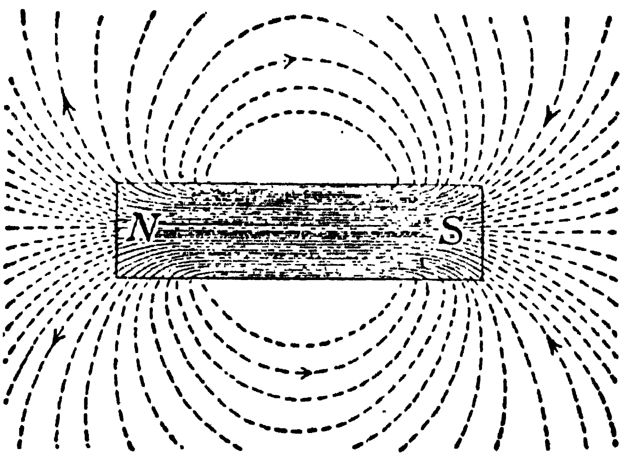


FIG. 11—Showing theoretical concepts of lines of force surrounding the poles of a bar magnet.

It would be incorrect, however, to think of these as actual lines extending through the space surrounding the magnet. The lines are only imaginary, and the idea of referring to magnetism in terms of *lines of force* has been adopted merely as a convenient means of expression when experimenting with magnets.

A better way of expressing this behavior would be perhaps to think of the lines of force as lines of stress, and that the magnet is in some way able to produce a strain in the medium about it, that this strain has a definite direction at every point, and consists of a tension in the direction of the lines of stress, and a repulsion at right angles to that direction.

Permanent and Temporary Magnets.—Certain substances like steel retain their magnetism after the magnetic field used to magnetize them has been removed, and are, therefore, called *permanent magnets.*

Other substanses, like soft iron, remain magnets only when they are in the field of another permanent magnet and become demagnetized after removal. Such magnets are called *temporary magnets.*

Analogy between Electric and Magnetic Circuits.—The total number of magnetic lines of force, or magnetic flux, produced in any magnetic circuit will depend upon the magnetomotive force (*m.m.f.*) acting on the circuit, just as the current in the electrical circuit depends upon the electromotive force and the resistance of the circuit.

The similarity between the electric and the magnetic circuit will readily be noted if Ohm's Law be applied to both. Thus, according to Ohm's Law:

$$\text{electric current} = \frac{\text{electromotive force}}{\text{resistance}}$$

$$\text{expressed in units, amperes} = \frac{\text{volts}}{\text{ohms}}$$

The resistance, as already explained, depends upon the materials of which the circuit is composed, and their geometrical shape and size.

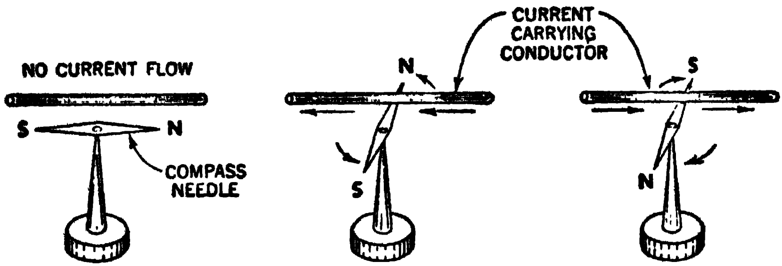
Similarly, in the magnetic circuit, the total number of magnetic lines produced by a given magnetizing solenoid depends upon the magnetomotive force, the material composing the circuit, and its shape and size. That is,

$$\text{magnetic flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}$$

$$\text{expressed in units, maxwells} = \frac{\text{gilberts}}{\text{oersteds}}$$

It should be noted that in the electric circuit, resistance causes heat to be generated, resulting in waste of energy; but in the magnetic circuit, reluctance does not involve any similar waste of energy.

Electromagnetism.—Back in the early part of the eighteenth century, a Danish physicist, Hans Christian Oersted discovered the effects of an electric current upon the magnetic needle. Oersted found while experimenting with the voltaic battery that when joining the wires from a battery above a suspended magnetic needle, that the compass needle instantly turned on its axis, and set itself at right angles to the wire. When the current was reversed the compass needle turned in the opposite direction.



FIGS. 12 to 14—Showing deflection of a compass needle held near a conductor through which an electric current flows.

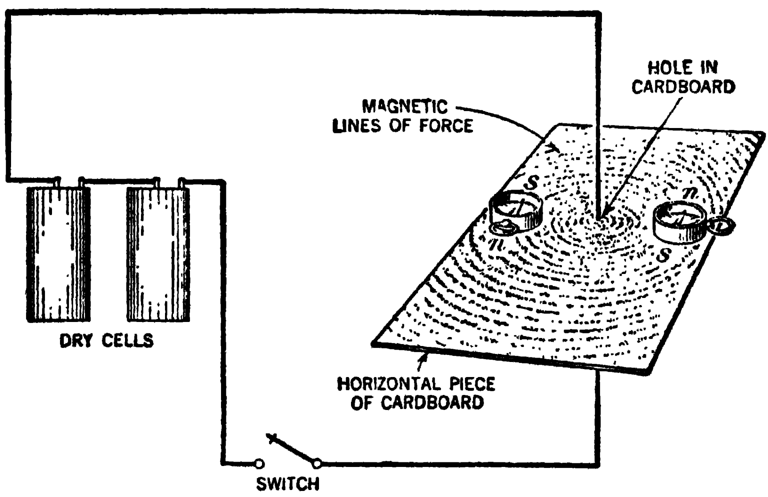


FIG. 15—Experiment showing direction of lines of force in the magnetic field surrounding a conductor carrying an electric current. A piece of copper wire is pierced through the center of a sheet of cardboard and carried vertically for two or three feet and then bent around to the terminals of a battery or other source of current. If iron filings be sprinkled over the card while the current is flowing, they will arrange themselves in circles around the wire, thus indicating the form of the magnetic field surrounding the conductor.

The magnetic effect of an electric current was further demonstrated by sending an electric current through a vertical wire which passes through a horizontal piece of cardboard filled with iron filings as shown in fig. 15.

By gently tapping the cardboard it will be found that the iron filings arrange themselves in concentric rings about the wire. An examination of the filings will show that each magnetic line forms a complete circle by itself. By placing small compasses at various positions on the cardboard it will be observed that the

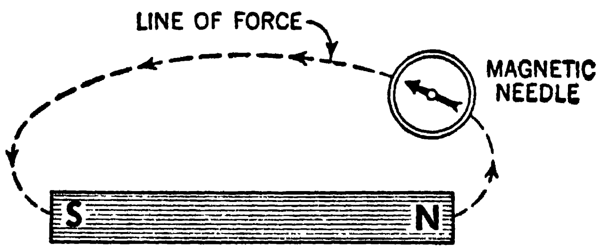


FIG. 16—Showing how lines of force may be traced by a magnetic needle. If a small magnetic needle be suspended by a thread and held near the magnet it will point in some fixed direction, depending on the proximity of the poles of the magnet. The direction taken by the magnet is called the direction of force at that point, and if the suspended needle be moved forward in the direction of the pole, it will trace a curved line which will start at one pole and end at the other. Any number of such lines can be traced. The space filled by these lines are called the magnetic field.

needles always point in a direction parallel to the circular magnetic lines. When the current flows through the wire as indicated, the needles will point in a counter-clockwise direction and if the current be reversed the needles will also reverse themselves, that is, they will point in a clockwise direction.

With these great discoveries it was conclusively shown that an electric current possesses magnetic properties, in that it can move a magnet and that a relationship exists between electricity and magnetism. It is perhaps true to say that these observations more than any other started a chain of events that has helped to shape our industrial civilization.

From the foregoing it is also clearly evident that a wire carrying an electric current acts like a temporary magnet and that magnetic lines of force in the form of concentric circles surround the wire and lie in planes perpendicular to the wire.

It was soon discovered that when several turns of wire were formed into a coil and current passed through it, that each turn added its magnetic field to the others, resulting in added magnetic strength. Such a magnet is called an *electromagnet.* Electromagnets are essential parts of electrical machinery, meters and instruments.

Ampere Turns.—In the construction of electromagnets, it is customary to wind the coil upon a soft iron core. When the coil is wound around the core several times, its magnetizing power is proportional both to the strength of the current and the number of turns in the coil. *The product of the current passing through the coil multiplied by the number of turns composing the coil is called the ampere turns.*

By experiments it has been established that the magnetomotive force in such a coil is

$$m.m.f. = 0.4\,\pi\, IN = 1.257\, IN, \text{ gilberts}$$

where I is the current in amperes and N the number of turns in the coil.

From the foregoing expression it follows that the strength of an electromagnet depends upon the product (IN) or ampere turns. Thus, for example, an electromagnet of 50 turns with one ampere flowing through it, has the same strength as an electromagnet of only 10 turns with 5 amperes flowing through it.

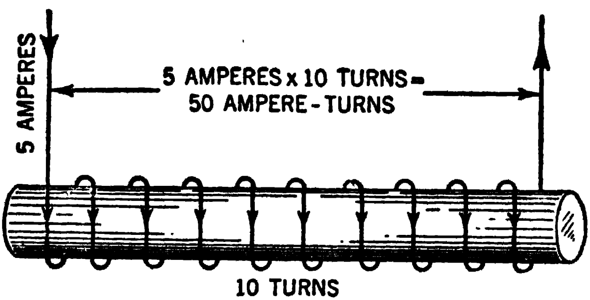


FIG. 17—Showing method of determining ampere-turns in a coil or electromagnet. Thus by measuring the current flow in amperes and multiplying with the number of turns in the coil, the product so obtained is called the ampere-turns of that coil.

Determination of Polarity.—There are several methods used to determine polarity of electromagnets. The simplest possible method is of course the employment of a permanent magnet such as a compass needle or any other magnet of known polarity. Thus if the North pole of a compass needle, for example, be brought into close proximity to one of the poles of an electromagnet of unknown polarity the action of the compass needle will immediately classify the pole as North or South depending upon whether the needle be repelled or attracted.

The Left-Hand Rule.—Another method for determining the polarity of an electromagnet is by means of the so-called *left-hand rule.* This simple rule consists in grasping the coil in the left hand with the fingers pointing in the direction of the current flow (assuming the current flowing from negative to positive) then the thumb points toward the North pole of the coil.

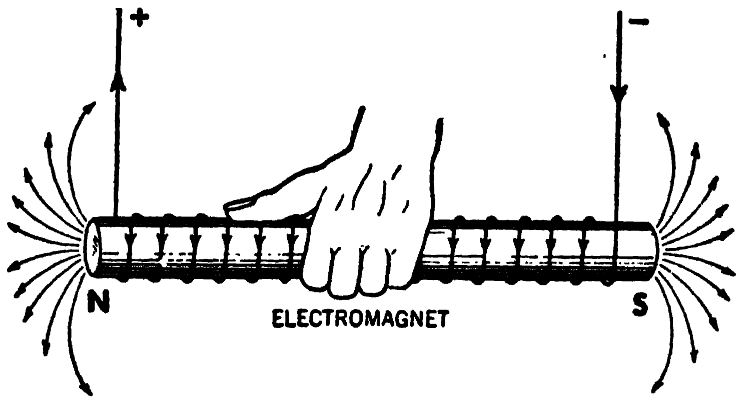


FIG. 18—Showing method of finding the polarity of a coil by means of the left-hand rule.

Relationship between Current Flow and Magnetic Lines of Force.—The direction of current flow versus the direction of lines of force may be found by encircling the conductor with the left hand, and with the thumb in direction of the current (assuming the direction of current from negative to positive), then the curled-up fingers will point in the direction that the lines of force are assumed to be taking in circling the conductor.

Horseshoe Magnets.—To facilitate the employment of magnets in practical devices such as in instruments, meters and the

like, it is customary to bend the magnet in the form of a horseshoe. In this manner the North and South poles will be brought adjacent to one another, thus projecting the magnetic lines of force in a direction perpendicular to the surface of the magnet as illustrated in fig. 7.

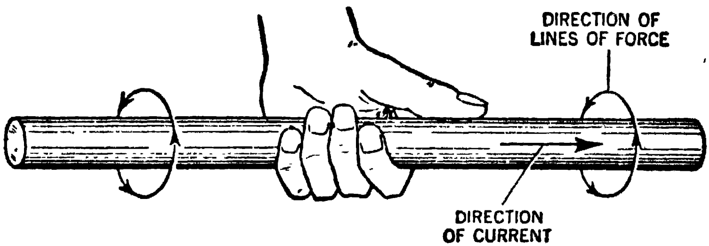


FIG. 19—Illustrating how the left hand rule may be used to determine direction in which lines of force encircle a current-carrying conductor.

Electromagnetic Induction

Early experimenters with electricity noted that if a closed circuit conductor such as a coil was moved in the vicinity of a magnet a current would flow in the circuit.

It was also found that a varying current in one conductor would cause a current to flow in a second conductor, provided the second conductor was brought close enough to the first one and a continuous path provided for the current flow. Such currents are said to be generated by *induction* and are termed *induced currents.* The combined action of induction and current flow is called *electromagnetic induction.*

It is the ability of an electromagnet to produce a current in a conductor which is responsible for the operation of motors and

generators. Electromagnetic induction is also employed in the transfer of electric energy from one circuit to another such as in transformers, used in the supply of power and light for homes and industry.

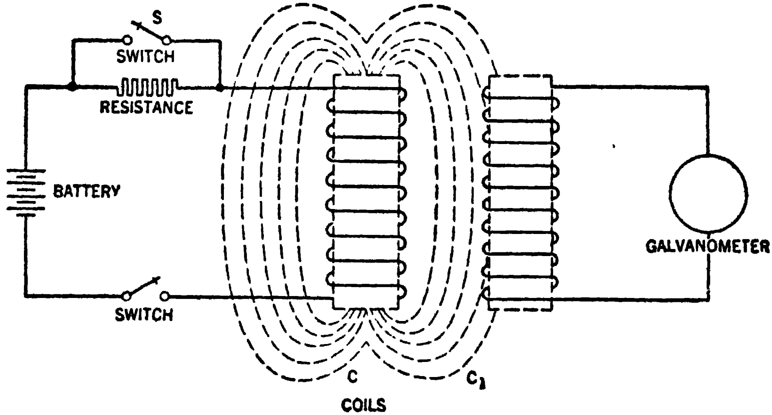


FIG. 20—Circuit showing how the effect of mutual induction may be measured by a galvanometer. If two coils C and C_1, be placed in axial relationship to one another as illustrated, and the current through coil C be varied by means of switch S, the induced current through coil C_1 will also be varied as indicated by the deflection of the galvanometer.

Direction of an Induced Current.—Various experiments have been made resulting in several rules or laws for determination of the direction of an induced current flow.

Laws of Induction.—These simple rules state (1) that *when an e.m.f. is induced in a closed circuit by a conductor cutting a field, or vice versa, the amount of current flow is proportional to the rate of cutting and the number of linkages.*

2. *The induced e.m.f. sets up a current the direction of which tends to prevent a change in the number of linkages.*

The foregoing statements have been combined and summarized into a law which may be stated as follows:

3. *An induced current has such a direction that its magnetic action tends to resist the motion by which it is produced. This is known as Lenz's Law.*

Measurement of Magnetism.—As previously noted, the magnetic lines of force are characterized by a closed loop, in which the path of the lines runs from the North to the South poles of the magnet and complete their circuit in the magnet itself. The space through which the lines of force act is called the *magnetic field.*

In connection with a study of magnetizm there are several units which are related to one another and which must be clearly understood. They are:

1. *The magnetic flux* (ϕ) is equal to total number of lines of force in a magnetic circuit and corresponds to the current in the electric circuit. The unit of flux is one line of force and is called *the maxwell.*

2. *The magnetomotive force* (*m.m.f.*) tends to drive the flux through the magnetic circuit and is similar to the electromotive force (*e.m.f.*) in the electric circuit. The unit of magnetomotive force is *the gilbert.*

3. *Reluctance* ($\mathcal{R}$) is the resistance offered by a substance to the passage of magnetic flux and corresponds to resistance in an electric circuit. The unit of reluctance is the *oersted.*

4. *Permanence* ($\mathcal{P}$) is the opposite of reluctance, and may be defined as the property of a substance which permits the passage of magnetic flux. It is the reciprocal of reluctance and corresponds to conductance of the electric circuit.

5. *Permeability* (μ) may be defined as the ratio of the flux existing in a certain substance to the flux which would exist if that material were replaced by air; the magnetomotive force acting upon this portion of the magnetic circuit remaining unchanged.

The permeability of air is therefore taken as unity or 1 (one). The permeability of certain types of iron is often more than 5,000 times that of air, varying with quality of the iron. It should also be noted that *the permeability of any substance increases with the increase of its cross-section and decreases with its length.*

Magnetization Curves.—These are frequently used to determine the number of ampere-turns required in an electromagnetic circuit when the magnetic material composing the circuit and other factors are known.

Thus to determine the ampere-turns required per inch of a magnetic circuit it is only necessary to know the flux density and permeability. If a curve, or curves be plotted, giving the direct relation between flux density B and ampere-turns required per inch H, of various magnetic materials, they will have the shape as noted in fig. 21.

Hysterisis.—The term hysterisis has been given to the action of lag of magnetic effect behind their source. Hysterisis thus means to "lag behind", hence its application to denote the lagging of magnetism in a magnetic material, behind the magnetic flux which produces it.

Hysterisis is caused by the friction between the molecules in a magnetic material which require an expenditure of energy to

align their position. This change of position or alignment takes place both in the magnetization and demagnetization process.

The amount of energy expended in the magnetization process and manifest by heat may be found by the use of a mathematical formula and is called the *hysterisis loss.*

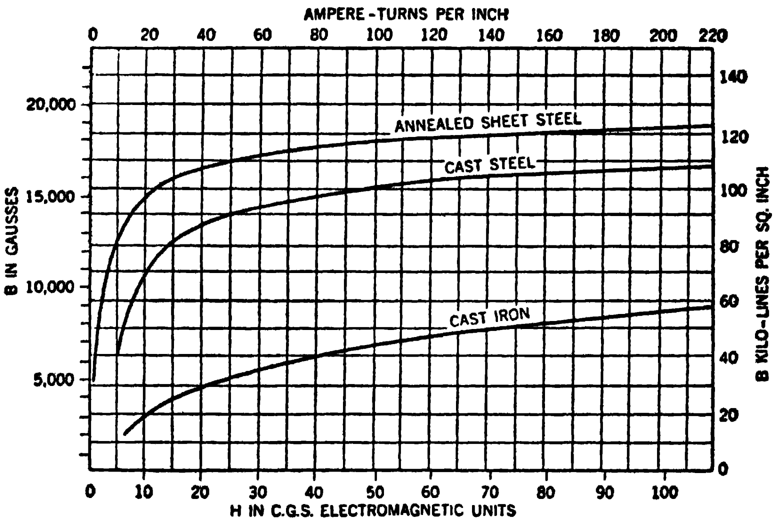


FIG. 21—Typical magnetization curves for cast iron, cast steel and annealed sheet steel.

This may best be understood by referring to the hysteresis loop or magnetic cycle shown in fig. 22, which shows how B changes when H is periodically varied. In the figure H, equals the number of lines of force per *sq. cm.* and B, equals number of lines of induction per *sq. cm.*

If now H be gradually diminished to zero it is found that the value of B, for any given value of H, is considerably greater

when that value of H, was reached by decreasing H from a higher value, than when the same value was reached by increasing H, from a lower value; that is to say, the curve AC when H is decreased, is very different from the curve OA, when it is increased.

Take for instance, the value of $H = 20$. When this is reached by increasing H from 0 to 20, the corresponding value of B is 5,100 but when it is reached by decreasing H from 94 to 20, the value of B is 12,200.

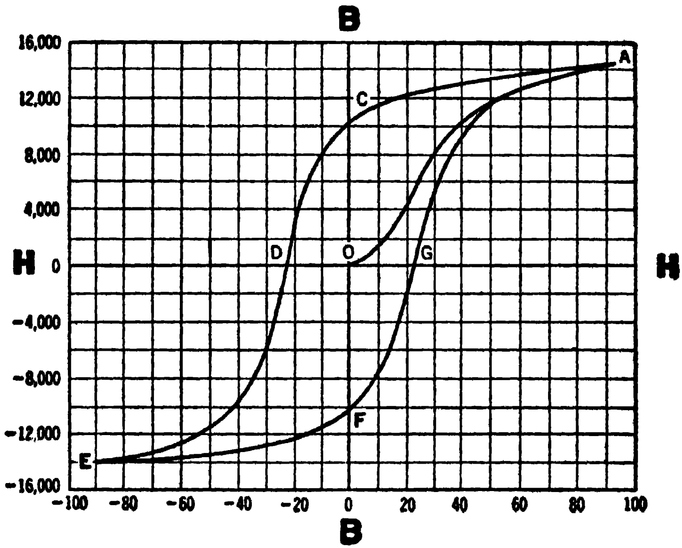


FIG. 22—A typical hysteresis loop.

It may be noted also that when H is reduced to zero, B, still has a value OC of 10,300 which is nearly three quarters the value it had when H, was 94. This induction is known as residual magnetism.

In soft iron it will nearly all disappear on tapping, but without this it can also be removed by reversing the current in the magnetization coil, so as to demagnetize the iron. The curve fig. 22 shows that a demagnetizing force of $H = 23$, is required to make B zero at point D. This force is called *coercive force* of the iron, and is a measurement of the tenacity with which it holds the residual magnetism.

As the magnetizing force is still further increased in the reverse direction, the curve passes from D to E, where the iron becomes saturated negatively. On gradually returning H to zero, the curve passes from E to F, along a similar but opposite path to AC, OF, because of the residual magnetism. The magnetizing force has now completed the cycle from O to a positive value, back to O, to a negative value and again back to O, and if this cycle be repeated several times, the B-H curve becomes a loop $FGACDE$, which loop is symmetrical about the center O.

The Electric Motor

Although electromagnets have found employment in a great variety of electrical devices, one of its most important uses is in the electric motor.

The electric motor principles can best be demonstrated by means of (1) a source of current such as a battery; (2) a horseshoe magnet and (3) a suspended coil of light copper wire arranged as shown in fig. 23.

If a current be sent through the coil it will commence to rotate through a right angle, and sets its faces opposite the poles of the magnet, but it will be found that it does not stop at the instant it reaches that position, but is carried beyond it.

The magnetic force and the torsional elasticity of the suspended cord, however, stops it and brings it back. After a few oscillations it settles into the position just mentioned, in which its line of force coincides with those of the magnet.

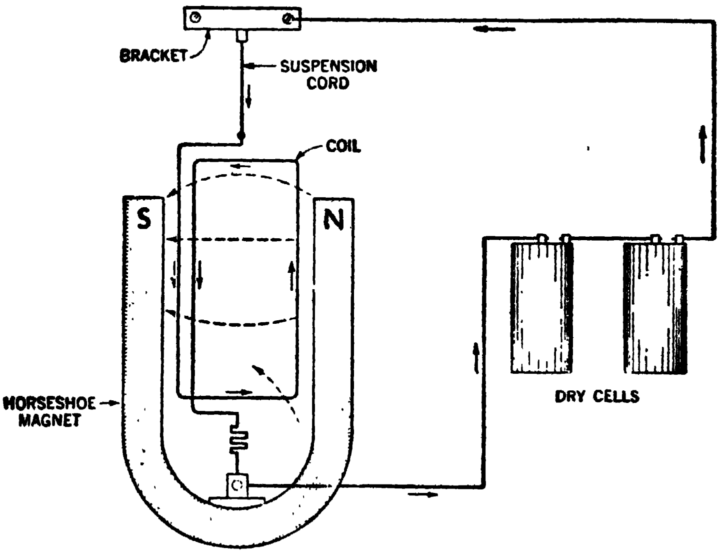


FIG. 23—Experimental circuit arrangement showing motor action of a suspended coil.

If we could manage to reverse the current just as it passes this position and if we also could free the coil from the torsion of the suspended cord, then instead of oscillating and settling in the position mentioned, it would go through half a revolution more. On account of its inertia, however, it cannot stop itself; and if we again reverse the current at the right instant, it will continue to rotate another half turn. From the foregoing it becomes evident that if the current be reversed exactly at the

end of each half turn, and the twisting force of suspension be eliminated a continuous rotation would be obtained.

To obtain continuous rotation therefore some means must be found to mechanically reverse the direction of the current at exactly the correct time, and also to free the coil so that it may rotate continuously without the hindrance of the suspension cord.

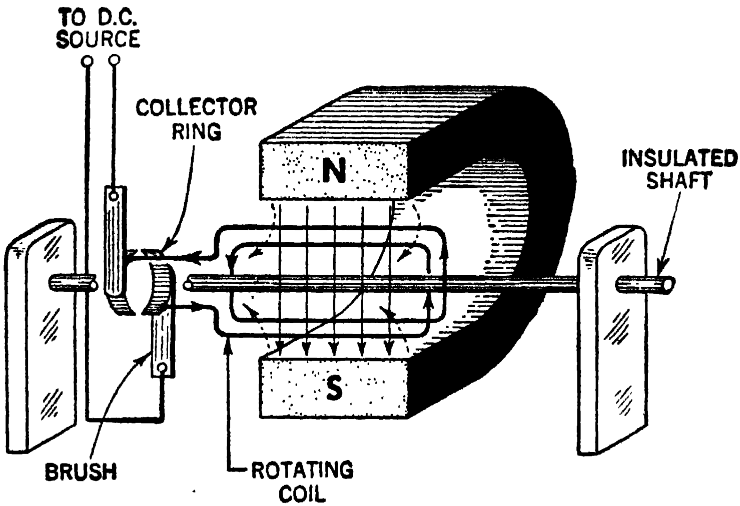


FIG. 24—Showing greatly simplified circuit arrangement where a coil may be made to rotate in a magnetic field.

This may easily be accomplished by mounting our copper wire coil, which may be called the armature on a horizontal steel axis or shaft whose ends are allowed to turn freely in suitable bearings. On this shaft and insulated from it, is mounted a metal ring that has been split and slightly separated in the middle as illustrated in fig. 24.

It will be noted that in order to complete our circuit it will be necessary to attach the two ends of the coil, one to each ring segment, and also to provide a connection to the current source. The latter will be accomplished by providing a couple of light metal springs each of which will be allowed to ride freely on diametrically opposite points of the split ring. The ends of the metal springs are finally attached to the current source.

Our apparatus is now completed and the coil rotates with its ring segments, and if the current be of sufficient strength the rotation will continue indefinitely. The early experimenters with electricity discovered the principle of the *direct current motor* in the foregoing manner.

In practical machines, the rotating coil is called *armature*, the ring segments *commutator*, the metal springs *brushes* and the permanent magnet is substituted for two or more *field coils*.

In summing up it will be noted that as the commutator rotates with the armature and when the armature is in one position, the electrons (or current) flows in through the negative brush to one half of the commutator, thence through the armature coil to the other half of the commutator and then out by means of the positive brush. However, as the armature makes another half turn, or revolution, so does each half of the commutator, which thereupon comes in contact with the opposite brush. The electrons now flow into the opposite half of the commutator and thus through the coil in the opposite direction. This reverses the poles of the armature and it continues its rotation.

Practical Direct Current Motors.—Although in the foregoing experiment the principles of the motor have been found, our

miniature motor is very weak and inefficient being barely able to run itself to say nothing of driving machinery.

In construction of a practical motor therefore, we may improve upon construction principles involved in the following manner:

1. Since the turning force acting upon our coil depends upon the two magnets, we may increase this force by making these magnets stronger.

2. Our knowledge of the permeability of soft iron suggests the application of a soft iron core upon which to wind or form our rotating coil.

3. We know that an electromagnet will provide a stronger magnetic field; so we can further increase the strength of the field by substituting electromagnets for the steel magnet.

4. The strength and efficiency of our magnet may be further improved if they be made shorter and thicker, with large pole pieces, shaped so as to embrace the coil as closely as possible without interfering with its rotation. This fills the air-gaps as nearly as possible with soft iron, and gathers in the lines of force, so that more of them pass through the armature.

5. The effectiveness of the armature may be greatly increased by winding on the iron core another coil at right angles to the first, so that when one coil is turning into the least effective position, the other is turning into the most effective position. The number of coils may be increased to four, six, eight and so on as illustrated in fig. 25, until all the available space on the core is filled. The commutator must also be constructed in such a way that each coil is

connected to its own segment. Increasing the number of coils not only increases the magnitude of the magnetic force, but also makes it approximately uniform in intensity.

This then, constitutes a direct current motor in modern form, and although improvements in materials, designs and efficiency are constantly sought, the motor in its present form leaves little to be desired in the matter of service in the multitude of tasks assigned to it.

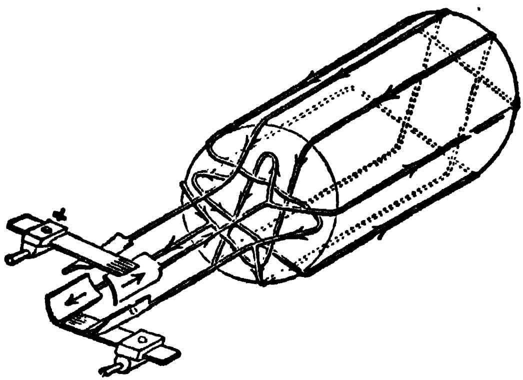
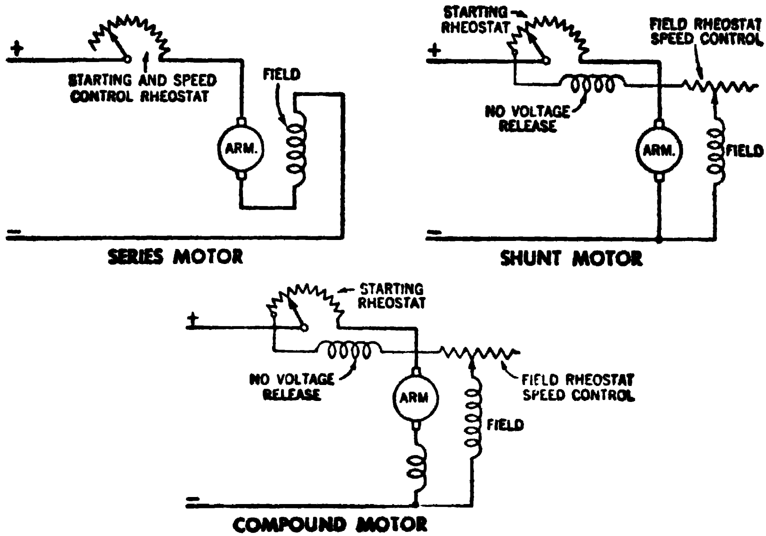


FIG. 25—Elementary four coil drum winding, showing the connections with the commutator segments and direction of currents in the several coils.

Direct Current Motor Connections.—Depending upon the connections between the field coils and armature, direct current motors are divided into three groups, and are classified as *series, shunt and compound wound.*

Thus, the *series motor* has derived its name from the fact that its *field* and *armature* are connected in *series* with one another. In a *shunt motor*, on the other hand, the *field* coils are connected in *shunt* or across the armature.

The compound motor, as the name implies, is actually connected as a combination of the series and shunt wound type and has two windings on its field poles, one having a relatively small cross-sectional area, connected across the armature in the manner of a shunt motor and the other winding connected in series with the armature.



FIGS. 26 to 28—Typical wiring diagrams showing internal connections of series, shunt and compound wound motors respectively.

Commutating Poles.—As an aid to commutation, and to prevent excessive sparking at the brushes, it is customary to provide larger motors with commutating or interpoles. These are located between the main field poles, the commutating field winding being connected in series with the armature. The *m.m.f.* of the commutating pole flux is opposite that of armature reaction. Thus the commutating pole flux induces a voltage

in the armature coils undergoing commutation in such a direction as to aid in reversing the current in those coils. Without this effect it would be difficult to obtain good commutation particularly in the larger machines.

Application of Direct Current Motors.—Since direct current is not usually available in most localities, *d.c.* motors are most commonly used in special applications, such as in certain types of hoisting machinery, on electrically or Diesel operated railroads, on electric motor drives requiring very close speed control, etc.

The trend towards the universal use of alternating current machinery is mainly one of economy since the cost of direct current motors is presently 150 to 300 per cent higher than those of squirrel cage induction motors of the same horsepower ratings. To this must also be added the cost of conversion from one type of current to another, which is usually accomplished by rectification of *a.c.* current, by synchronous converters or by motor generator sets.

The procedure of calculation will be illustrated by considering the following:

Example.—*A* 50 *HP*, 500 *volt, shunt motor draws a line current of* 4.5 *amperes at no load. The shunt field resistance is* 250 *ohms and the armature resistance exclusive of brushes is* 0.3 *ohm. The brush drop is* 2 *volts. The full load line current is* 84 *amperes. What is the horsepower output and efficiency at* 84 *amperes?*

Solution.—From data supplied, we obtain,

$$I_a = I_L - I_f = 84 - \frac{500}{250} = 82 \text{ amperes}$$

At no load,

$$I_a = I_L - I_f = 4.5 - \frac{500}{250} = 2.5 \text{ amperes}$$

Stray power loss,

$$P_{sp} = 2.5 \times 500 = 1{,}250 \text{ watts}$$

Brush loss

$$= 2 \times I_a = 2 \times 82 = 164 \text{ watts}$$

and from equation

$$\eta_m = \frac{500 \times 84 - (82^2 \times 0.3 + 500 \times 2 + 164 + 1{,}250)}{500 \times 84}$$

$$= \frac{42{,}000 - 4{,}431}{42{,}000} = \frac{37{,}569}{42{,}000} = 0.8945 \text{ or } 89.45\%. \quad \textit{Ans.}$$

$$\text{Horsepower output} = \frac{37{,}569}{746} = 50.36 \quad \textit{Ans.}$$

Example.—*A* 65 *volts shunt-wound generator is delivering* 30 *amperes at* 65 *volts. The armature resistance is* 0.04 *ohm and that of the shunt field* 20 *ohms. If the stray power losses be neglected,*

Calculate

(*a*) *Current through the field*
(*b*) *Current through the armature*
(*c*) *E.m.f. of the armature*
(*d*) *Copper losses in the armature winding*
(*e*) *Copper losses in the field winding*
(*f*) *Efficiency when the line current is* 30 *amperes*

Solution.—

(a) $$I_f=\frac{V_t}{R_f}=\frac{65}{20}=3.25 \text{ amperes.} \quad \textit{Ans.}$$

(b) $$I_a=I_L+I_f=30+3.25=33.25 \text{ amperes.} \quad \textit{Ans.}$$

(c) $$E_a=V_t+I_aR_a=65+33.25\times0.04=66.33 \text{ volts.} \quad \textit{Ans.}$$

(d) $$I^2_aR_a=33.25^2\times0.04=44.2 \text{ watts.} \quad \textit{Ans.}$$

(e) $$V_tI_f=65\times3.25=211.25 \text{ watts.} \quad \textit{Ans.}$$

(f) $$\eta_0=\frac{V_tI_L}{V_tI_L+V_tI_f+I_a^2R_a}=\frac{65\times30}{65\times30+211.25+44.2}$$

$$=0.884 \text{ or } 88.4\%. \quad \textit{Ans.}$$

Example.—*A motor requires* 10 *kilowatts to enable it to supply its full capacity of* 10 *horsepower to its pulley. What is its full load efficiency?*

Solution.—

$$\text{Efficiency}=\frac{\text{output}}{\text{input}}=\frac{10\times746}{10{,}000}=0.746 \text{ or } 74.6\%. \quad \textit{Ans.}$$

TEST QUESTIONS

1. *What is magnetism?*
2. *What is a lodestone (incorrectly spelled loadstone)?*
3. *Describe two kinds of magnetism, explaining nature of each.*

4. *In what regions is the magnetism strongest?*
5. *How are magnetic poles designated, and what is the feature of each?*
6. *Describe a magnetic field, and define the magnetic lines of force.*
7. *State two laws of magnetic force.*
8. *What is a magnetic circuit?*
9. *Define magnetic flux, and how it is measured?*
10. *Define magnetic flux; reluctance; oersted; maxwell; gauss.*
11. *Describe Oersted's discovery.*
12. *Give the following rules: corkscrew; right hand; Ampere's.*
13. *What is a solenoid?*
14. *Give the right hand rule and clock rule as applied to solenoids.*
15. *Describe the action of an iron core in a solenoid.*
16. *What is permeability and magnetic saturation?*
17. *What are ampere turns and the rule relating to them?*
18. *Define reluctance.*
19. *Give analogy between electric and magnetic circuits.*
20. *State rules for reluctance.*
21. *What is hysteresis and its cause?*
22. *What data did Ewing give?*
23. *What is residual magnetism and what important use is made of same?*
24. *State Ewing theory of magnetism.*

CHAPTER 10

Electro-Magnetic Induction

The tendency of electric currents to flow in a conductor when it is moved in a magnetic field so as to ***"cut" lines of magnetic force*** is known as electro-magnetic induction.

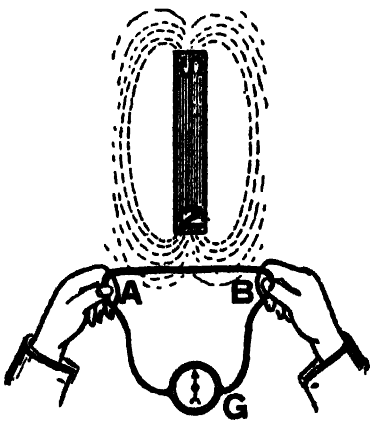


FIG. 303.—***Faraday's discovery:*** If a loop of wire be connected to a galvanometer and a section of the wire AB, be moved through a magnetic field as shown, the galvanometer will be deflected indicating that an electric current is generated when ***a conductor is moved in a magnetic field so as to cut lines of force.*** A thorough understanding of the term ***cut lines of force*** is highly important.

Faraday discovered that *if he took a wire, joined its ends and moved it in front of a magneto, a current would be induced in the wire*. The current is called the *induced*

current and that part of the wire moved in the magnetic field, the *inductor*.

All dynamos of whatever form, are based upon this discovery made by Faraday in 1831, which in rule form is as follows:

FARADAY'S DISCOVERY—*Electric currents are induced in inductors* by moving them in a magnetic field, so as to cut magnetic lines of force.*

Ques. Explain the expression "cut lines of force."

Ans. A conductor, forming part of an electric circuit, *cuts lines of force* when it moves across a magnetic field in such manner as to *alter* the number of magnetic lines of force which are embraced by the circuit.

It is important to clearly understand the meaning of this expression, which will be later explained in more detail.

Faraday's Machine.—After various experiments, Faraday made his "new electrical machine" as shown in fig. 304. This piece of apparatus is preserved and was shown in perfect action by Prof. S. P. Thompson in a lecture delivered April 11th, 1891, after an interval of sixty years.

It consists of a horse shoe magnet and a copper disc attached to a shaft and supported so as to turn freely. The magnet is so placed that

*NOTE.—A wire or other conductor moving in a magnetic field to induce an electric current is properly called an ***inductor***.

NOTE.—***Michael Faraday***, born 1791, died 1867. He was an English scientist, famous for his discoveries in chemistry, electricity and magnetism. He first produced the rotation of the magnetic needle around the electric circuit (1821) based upon Oersted's discovery of electro-magnetism in 1820; he discovered electro-magnetic induction (1831), a principle upon which is founded the development of dynamo machinery; specific inductive capacity (1838), magnetic polarization of light (1845); diamagnetism (1846). He was a brilliant experimenter, and contributed greatly to the knowledge upon which is based present day practice of electricity.

its inter-polar lines of force traverse the disc from side to side. There are two copper brushes, one bears against the shaft, and the other against the circumference of the disc. A handle serves to rotate the disc in the magnetic field.

Now, if the north pole of the magnet be nearest the observer and the disc be rotated clockwise, the current *induced* in the circuit will flow out at the brush which touches the circumference, and return through the brush at the shaft.

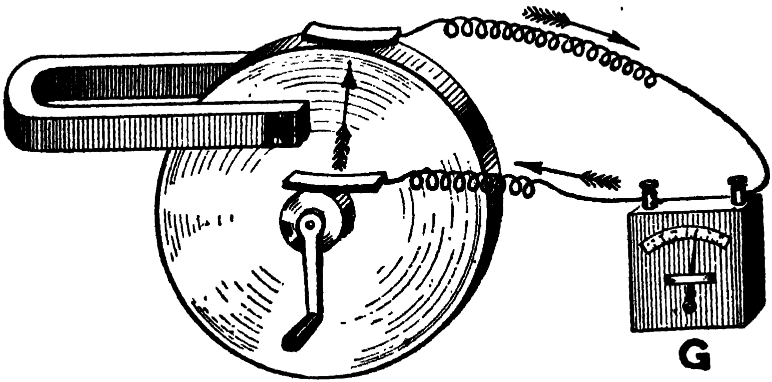
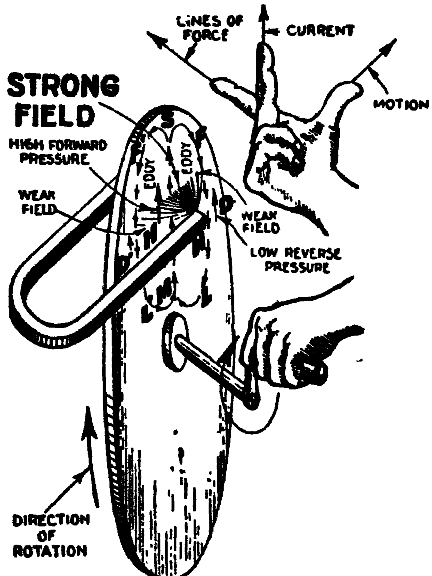
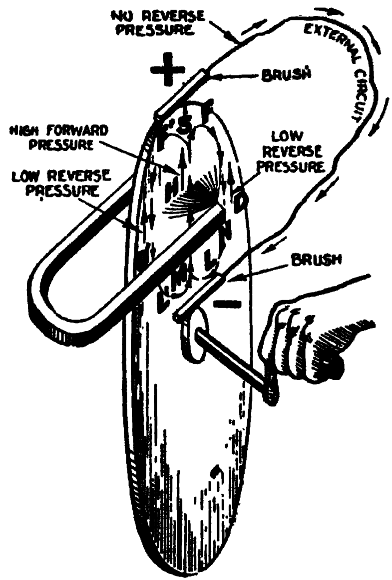


FIG. 304.—Faraday's dynamo which embodies his discovery in 1831 of *electromagnetic induction*, the principle upon which all dynamos work, as well as induction coils, transformers, and other electrical apparatus.

Faraday's Principle.—The principle deduced from Faraday's experiment may be stated as follows:

*When a conducting circuit is moved in a magnetic field so as to "**cut**," that is **alter** the number of lines of force passing through it, a current is induced therein, in a direction at right angles to the direction of the motion, and at right angles also to the direction of the lines of force, and to the right of the lines of force, as viewed from the point from which the motion originated.*



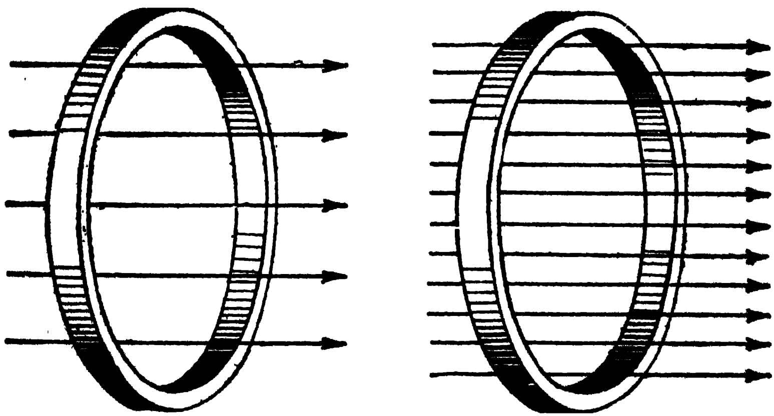


FIGS. 305 and 306.—How Faraday's dynamo works. *In operation*, as the disc is turned clockwise any (radial) element as MS, as it moves across the field will cut magnetic lines, which will induce a current upward in direction as determined by applying Fleming's rule (as applied in fig. 395). *The inductive action is strongest at the center of the field, hence as MS, passes the center (position shown), the induced pressure along MS, is greater than along some other element as LF, or L'F', more or less remote from the center*; that is, induced pressure H, in the strong field is greater than induced pressure D, or D', in the weak fields. Accordingly H, overbalances the two opposing weak pressures D and D', and results in a pair of eddy currents as shown. Now, if brushes be placed so that one bears against the hub and the other against the circumference of the disc and connected by a wire, some of the eddy currents will flow out in the external circuit, because the external circuit cuts no lines of force, and accordingly no reverse pressure (such as D or D') is induced therein.

Faraday's principle may be extended as follows to cover all cases of electromagnetic induction:

When a conducting circuit is moved in a magnetic field, so as to alter the number of lines of force passing through it, or when the strength of the field is varied so as to either increase or decrease the number of lines of force passing through the circuit, a current is induced therein which lasts only during the interval of change in the number of lines of force embraced by the circuit.

Ques. Explain just what happens when a current is induced by electromagnetic induction.



FIGS. 307 and 308.—Current induced in conducting circuit by *altering the field strength.*

Ans. In order to induce an electromotive force by moving a conductor across a uniform magnetic field, it is necessary that the conductor, in its motion, should so cut the magnetic lines as to alter the number of lines of force that pass through the circuit of which the moving conductor forms a part.

Ques. What is the proper name for a "conductor" which moves across the magnetic field?

Ans. An *inductor*, because it is that part of the electric circuit in which induction takes place.

In the case of a dynamo, an inductor may be either a copper wire or copper bar.

Ques. How may a conducting circuit be moved across a magnetic field without having a current induced therein?

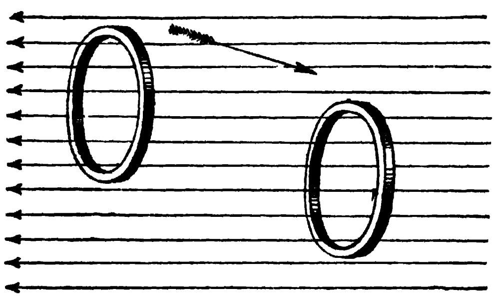


FIG. 309.—Electromagnetic induction *1: In order to* induce a current by electro-magnetic induction, an inductor must be so moved through a magnetic field *that the number of lines of force passing through it (that is, embraced) is altered.* If a coil be given a simple motion of translation in a uniform magnetic field as indicated in the figure, *no current will be induced because the number of lines of force passing through it are not changed*, that is, during the movement as many lines are lost as are gained.

Ans. If a conducting circuit, for instance, a wire ring or single coil, be moved in a uniform magnetic field, as shown in fig. 309, so that only the same number of lines of force pass through it, no current will be generated, for since the coil is moved by a motion of translation to another part of the field, as many lines of force will be left behind as are gained in advancing from its first to its second position.

Ques. Describe another movement by which no current will be induced.

Ans. If the coil be merely rotated on itself around a central axis, that is, like a fly wheel rotating around a shaft, as in fig. 310, the number of lines of force passing through the coil will not be altered, hence no current will be generated.

Ques. State the essential condition for current induction in a uniform field.

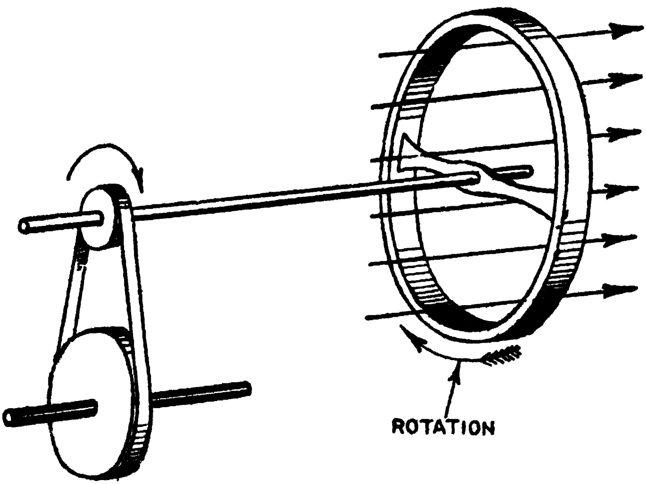


FIG. 310.—Rotation of coil without inducing any current therein.

Ans. The coil in which a current is to be induced, must be tilted in its motion across the uniform field, or rotated around any axis in its plane as in fig. 311, *so as to alter the number of lines of force which pass through it.*

Ques. In what direction will the current flow in the coil, fig. 311?

Ans. The current induced in the coil will flow around it in a clockwise direction (as observed by looking along the magnetic field in the direction in which the magnetic lines run) if the effect of the movement be to diminish the number of lines of force that pass through the coil. The current will flow in the opposite direction (counter-clockwise) if the movement be such as to increase the number of intercepted lines of force.

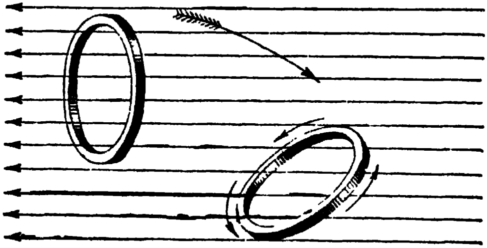


FIG. 311.—Electro-magnetic induction 2: If a coil be given a motion of rotation from any point within its own plane in passing through a uniform magnetic field, *a current will be induced in the coil because the number of lines of force passing through it is altered.*

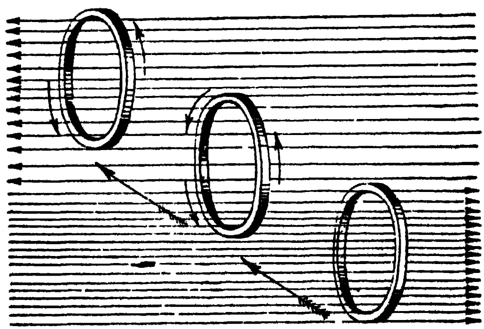
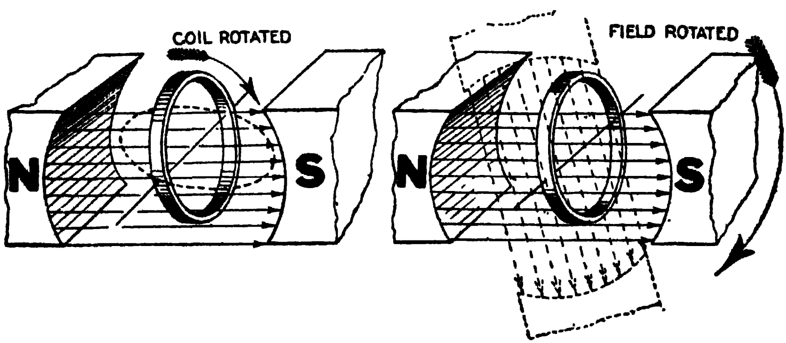


FIG. 312.—Electro-magnetic induction 3: If a coil be given a simple motion of translation in a ***non-uniform*** or ***variable*** magnetic field, *a current will be induced in the coil, whether the motion be from the dense to the less dense region of the field or the reverse, because the number of lines of force passing through the coil is altered.*

Ques. If the magnetic field be not uniform, as in fig. 312, what will be the result?

Ans. The effect of moving the coil by a simple motion of translation from a dense region of the field to one less dense, or vice versa, will be to induce a current because in either case, the number of lines of force passing through the coil is altered.*

Laws of Electro-magnetic Induction.—There are certain laws of electro-magnetic induction which, on account of the



FIGS. 313 and 314.—*Law 1.* Current induced 1, by rotation of coil (fig. 313), and 2, by rotation of field (fig. 314). *Motion is purely a relative matter,* and it makes no difference electrically whether the coil rotate, or the field rotate.

importance of the subject, it is well to carefully consider. The facts presented in the preceding paragraphs are embodied in the following fundamental laws:

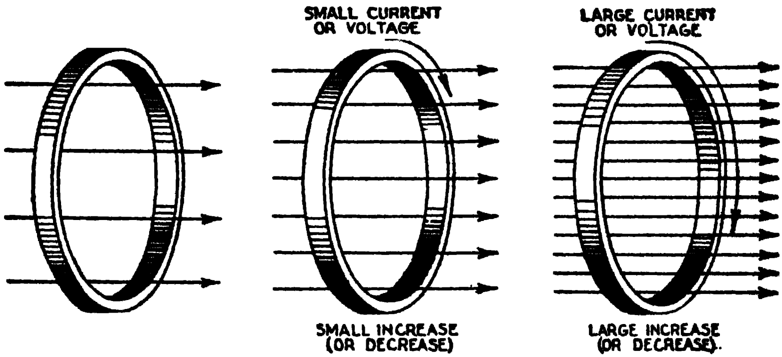
Law 1.—FARADAY'S DISCOVERY—*To induce a current in a circuit, there must be a relative motion between the circuit and a magnetic field, of such a kind as to alter the number of magnetic lines embraced in the circuit.*

*NOTE.—*The term altered* should be understood. *The lines of force passing through a coil are altered when they are either increased or decreased in number.*

Law 2.—*The voltage (or current) induced in a circuit is proportional to the rate of increase or decrease in the number of magnetic lines embraced by the circuit.*

For instance, if n, equal the number of magnetic lines embraced by the circuit at the beginning of the movement, and n', the number embraced after a very short interval of time t, then

$$\text{the average induced voltage} = \frac{n - n'}{t}$$



FIGS. 315 to 317.—*Law 2.* Relation between increase (or decrease) of field and voltage or current induced.

It would require the cutting of about 100,000,000 lines per second to produce voltage equal to that of one Daniell cell.

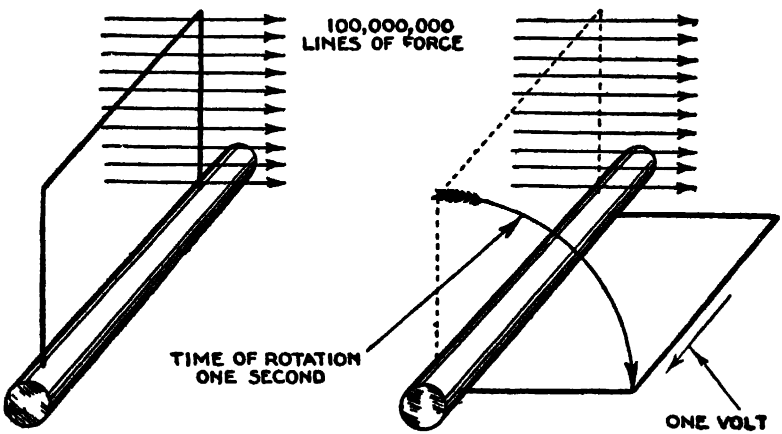
The unit of electric pressure, called the *volt*, is the electric pressure produced by cutting 100,000,000 lines per second, usually expressed 10^8.

Law 3.—*When a straight wire cuts 100,000,000 lines of force at right angles per second, an electric pressure of one volt is induced.*

Law 4.—*By joining in series a number of inductors or coils moving in a magnetic field, the electric pressures in the separate parts are added together.*

The reason for this is apparent by considering a coil of wire having several turns and moving in a magnetic field so as to cut magnetic lines. During the movement, the lines cut by the first turn are successively cut by all the other turns of the coil, hence, the total number of lines cut is equal to the number cut by a single turn multiplied by the number of turns. The pressures induced in the separate turns are therefore added.

Example.—If a coil of wire of 50 turns cut 100,000 lines in $^1/_{100}$ of a second, what will be the induced voltage?



Figs. 318 and 319.—*Law 3.* Conditions for generating one volt pressure.

The number of lines cut per second per turn of the coil is

$$100{,}000 \times 100 = 10{,}000{,}000$$

The total number of lines cut by the coil of 50 turns is

$$10{,}000{,}000 \times 50 = 500{,}000{,}000$$

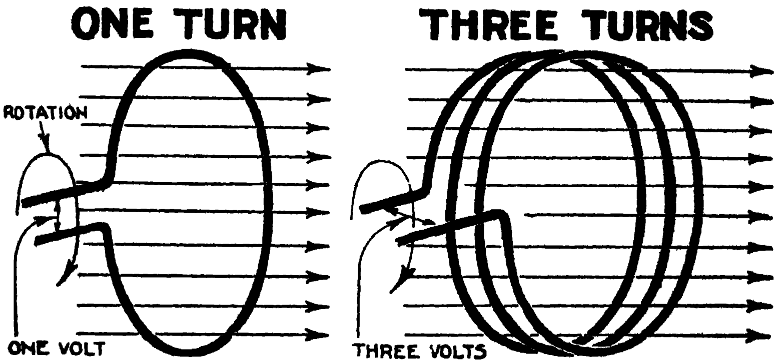
which will induce a pressure of

$$500{,}000{,}000 \div 10^8 = 5 \text{ volts}$$

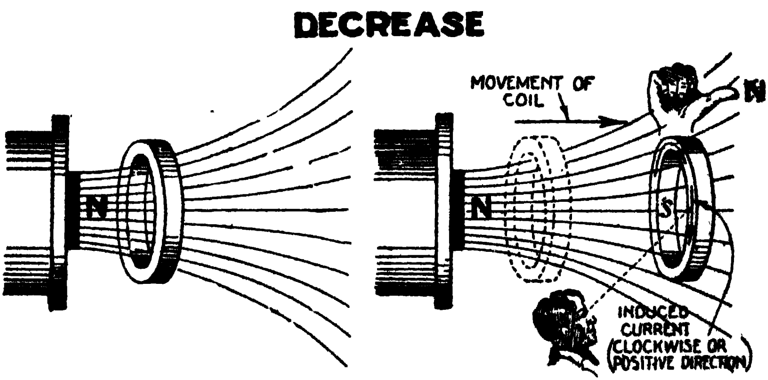
Law 5.—*A decrease in the number of magnetic lines which pass through a circuit induces a current around the circuit in the positive direction.*

NOTE.—The term ***positive direction*** is understood to be the direction along which a free N pole would tend to move.

Law 6.—*An increase in the number of magnetic lines which pass through a circuit induces a current in the negative direction around the circuit.*



FIGS. 320 and 321.—*Law 4.* Relation between number of turns of coil and voltage generated.



FIGS. 322 and 323.—*Law 5.* Effect of *decrease* in number of lines of force passing through a conducting circuit.

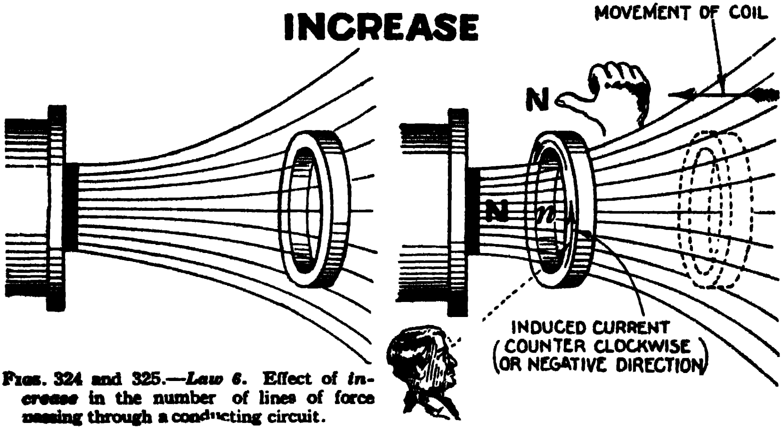
The reason for the change of direction of the current for decrease or increase in the number of lines cut, as stated in the fourth and fifth laws. will be seen by aid of the formula given under the second law, viz:

$$\text{electromotive force} = \frac{n - n'}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

but by Ohm's law

$$\text{current} = \frac{\text{electromotive force}}{\text{resistance}} \text{ or, } I = \frac{E}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Substituting (1) in (2)



FIGS. 324 and 325.—*Law 6.* Effect of *increase* in the number of lines of force passing through a conducting circuit.

$$\text{current} = \frac{\frac{n - n'}{t}}{R} \text{ or, } \frac{n - n'}{Rt}. \quad (3)$$

Now in equation (3) if there be a *decrease* in the number of lines cut, n', will be less than n, hence the current will be positive (+); again, if the lines *increase*, n', will be greater than n, which will give a minus value, that is, the current will be negative or in a reverse direction.

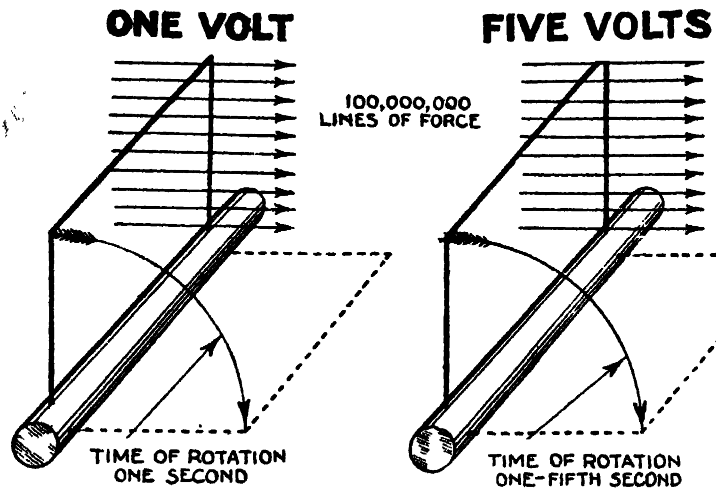
Law 7.—***The approach and recession of a conductor from a magnet pole will yield currents alternating in direction.***

NOTE.—***The direction of the induced current*** in figs. 322 to 325 is easily determined by applying Lenz law and the right hand rule for polarity. Since there is opposition to the movement of the coil, there will be *unlike* poles when the coil recedes (fig. 323) and *like* poles when the coil approaches the magnetic pole.

Since the strength of the field depends on the proximity to the pole, the approach and recession of a conductor involve an *increase* and *decrease* in the rate of cutting of magnetic lines, hence a reversal of current.

Law 8.—*The more rapid the motion, the higher will be the induced electromotive force.*

In other words, the greater the number of lines cut per unit of time, the higher will be the voltage.



Figs. 326 and 327.—*Law 7.* Relation between rate of cutting the lines of force and voltage generated.

Law 9.—*Lenz's law. The direction of the induced current is always such that its magnetic field opposes the motion which produces it.*

This is illustrated in figs. 328 and 329.

Rules for Direction of Induced Current.—There are a number of rules to quickly determine the direction of an induced current when the direction of the lines of force, and motion of the inductor are known. The first rule here given was devised by Fleming and is very useful. It is sometimes called the "dynamo rule."

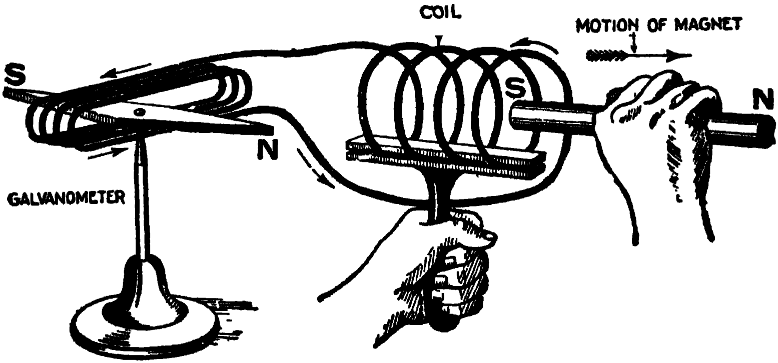


FIG. 328.—Experiment illustrating Lenz's law which states that in all cases of electro-magnetic induction, *the direction of the induced current is such as to tend to stop the motion producing it.* ***In the experiment,*** in order to produce the induced current, energy must be expended in bringing the magnet to the coil and in taking it away, which is in accordance with the law of conservation of energy.

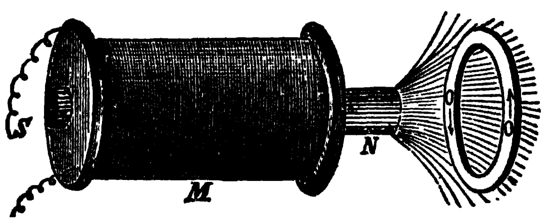
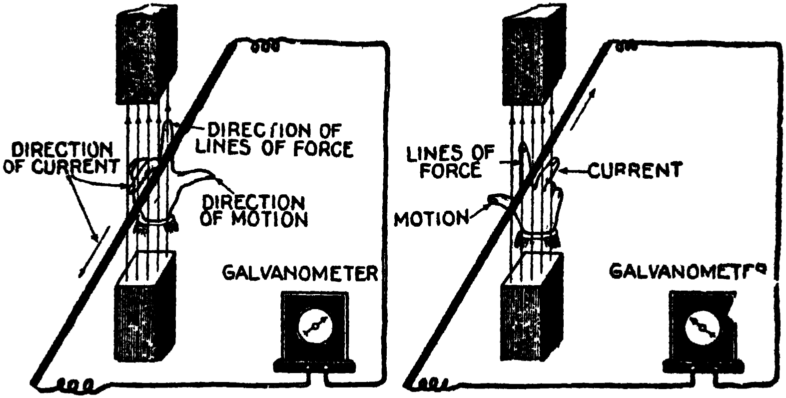


FIG. 329.—Experiment illustrating Lenz's law. If a copper ring be held in front of an ordinary electro-magnet, and the current circulating through the coil of the magnet be in such a direction as to magnetize the core as indicated by the letters S,N, then as the current increases in the coil more and more of the lines of force proceeding from N, pass through the ring OO, from left to right. While the field is thus increasing, current will be induced in the copper ring in the direction indicated by the arrows, such currents tending to set up a field that would pass through the ring from right to left, and would therefore *retard* the growth of the field due to the electro-magnet M.

Fleming's Rule.—*If the forefinger of the right hand be pointed in the direction of the magnetic lines, and the thumb (at right*



FIGS. 330 and 331.—Fleming's rule for direction of induced current. *Extend the thumb, fore finger and middle finger of the right hand so that each will be at right angles to the other two. Place the hand in such position that the thumb will point in the direction in which the inductor moves, the forefinger in the direction of the lines of force (N to S), then will the middle finger point in the direction in which the induced current flows.* This is a very useful rule and the author recommends that it be thoroughly understood.

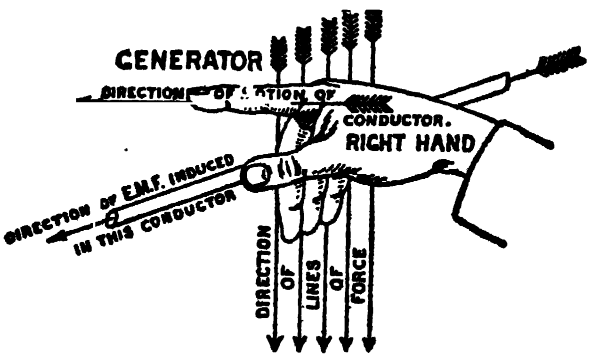


FIG. 332.—A rule for direction of induced current which, in some cases, is more conveniently applied than Fleming's rule: *Hold the thumb, forefinger and remaining fingers of the right hand at right angles to each other; place the hand in such position that the forefinger points in the direction of motion of the inductor, the three fingers in the direction of the lines of force, then will the thumb point in the direction of the induced current.*

angles to the forefinger) be turned in the direction of the motion of the conductor, then will the middle finger, bent at right angles to both thumb and forefinger, show the direction of the induced current.

The application of this rule is shown in figs. 331 and 332. The right hand is so placed at the north pole of a magnet, that the forefinger points in the direction of the magnetic lines; the thumb in the direction of motion of the conductor; the middle finger pointed at right angles to the thumb and forefinger, indicates the direction of the current induced in the conductor.

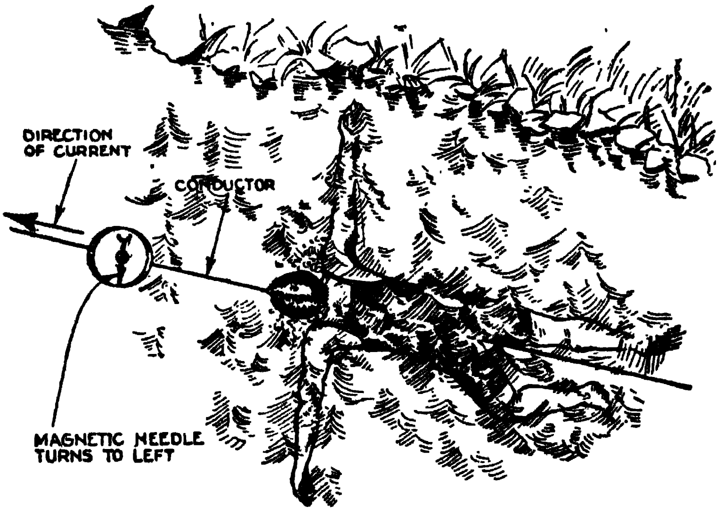


FIG. 333.—Imaginative view of man swimming "in a conductor" illustrating Ampere's rule.

Ampere's Rule.—*If a man could swim in a conductor with the current, then the north seeking (+) pole of a magnetic needle placed directly ahead of him, will be deflected to the left, while the south seeking (—) pole will be urged to the right.*

For certain particular cases in which a fixed magnet pole acts on a movable circuit, the following converse to Ampere's rule will be found useful: If a man swim in the wire with the current, and turn so as to look

along the direction of the lines of force of the pole (that is, as the lines of force run, *from* the pole if it be north seeking, *toward* the pole if it be south seeking), then he and the conducting wire with him will be urged *toward his left.*

The Palm Rule.—*If the palm of the right hand be held facing or against the lines of force, and the thumb in the direction of the*

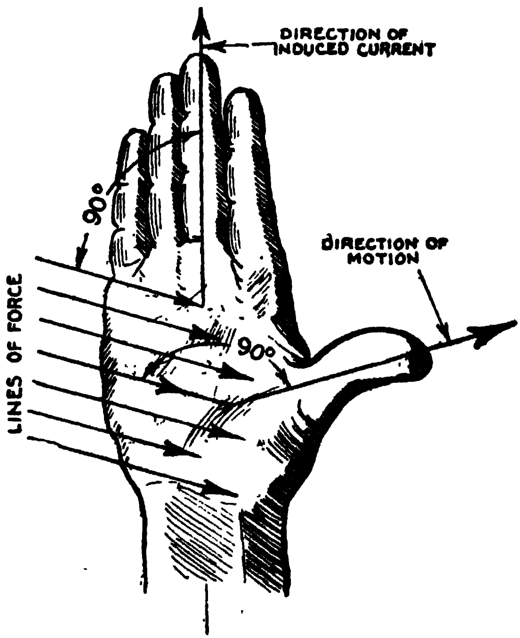


FIG. 334.—The palm rule for direction of induced current: *If the palm of the right hand be held against the direction of the lines of force, the thumb in the direction of the motion, then the fingers will point in the direction of the induced current.*

motion, then the fingers will point in the direction of the induced current.

Self-induction.—This term signifies *the property of an electric current by virtue of which it tends to resist any change of value.*

Self-induction is sometimes spoken of as *electromagnetic inertia*, and is analogous to the mechanical inertia of matter.

It is on account of self-induction of the induced currents in the armature winding of a dynamo, that sparks appear at the brushes when the latter are not properly adjusted, hence the importance of clearly understanding the nature of this peculiar property of the current.

Self-induction is fully explained in the chapter following.

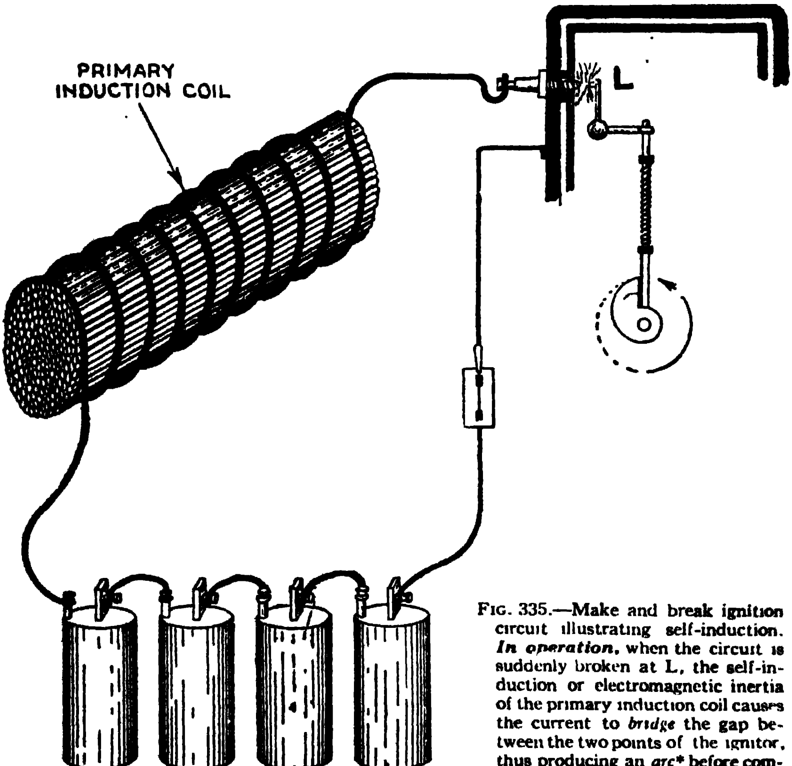


FIG. 335.—Make and break ignition circuit illustrating self-induction. *In operation*, when the circuit is suddenly broken at L, the self-induction or electromagnetic inertia of the primary induction coil causes the current to *bridge* the gap between the two points of the ignitor, thus producing an *arc** before coming to rest.

*NOTE.—Careful distinction should be made between the terms *arc* and *spark*. An arc *bridges* the gap; a spark *jumps* the gap.

TEST QUESTIONS

1. *Define electro-magnetic induction.*
2. *What is the difference between a conductor and an inductor?*
3. *Define precisely the term "cut lines of force."*
4. *State Faraday's discovery, and describe his machine.*
5. *State the principle deduced from Faraday's experiment.*
6. *Explain how a current is induced by electro-magnetic induction.*
7. *Explain how an inductor may be moved in a magnetic field.* ***a,*** *to induce,* ***b,*** *not to induce, a current.*
8. *What is the direction of the induced current?*
9. *State the laws of electro-magnetic induction; give examples.*
10. *Give the following rules for the direction of induced current: Fleming's; Ampere's; palm.*
11. *What is self induction?*
12. *What causes sparks at the brush of a dynamo?*

CHAPTER 11

Induction Coils

The induction coil has always been a popular piece of apparatus with those interested in electrical science; the experiments which can be performed with its aid are very numerous.

It is of considerable importance, especially in its application to such useful purposes as X-ray work, wireless telegraphy and *ignition* for gas engines. The latter has caused manufacturers to give much attention to the development of the induction coil, resulting in many refinements of design and construction.

Induction coils may be divided into two general classes:

1. ***Primary*** *coils;*
2. ***Secondary*** *coils.*

The subject of electro-magnetic induction has been fully explained in Chapter 10, but it may be said, with special reference to induction coils, that the operation of the two classes just mentioned is respectively due to:

1. ***Self*** *induction;*
2. ***Mutual*** *induction.*

Self Induction.—This is the property of an electric current by virtue of which ***it tends to resist any change in its rate of flow.***

It is sometimes spoken of as *electromagnetic inertia* and is analogous to the mechanical inertia of matter.

Self-induction is due to the action of the current upon itself during variations in strength.

It becomes especially marked in a coil of wire, in which the adjacent turns act inductively upon each other upon the principle of *mutual induction* arising between two separate adjacent circuits.

Self-induction manifests itself by giving "*momentum*" to the

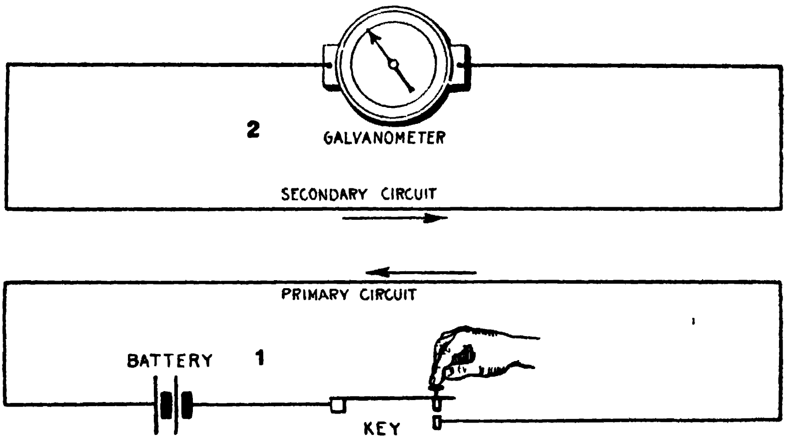


FIG. 336 and 337.—Diagram showing the action of mutual induction between two circuits; the one including a source of electrical energy and a switch; the other including a galvanometer, but having no cell or other electrical source. During the increase or decrease in the strength of the current as on closing or opening the key a current is *induced* in the secondary circuit in a direction opposite to that of the primary current as indicated by the arrows.

current so that *it cannot be instantly stopped when the circuit is broken*, the result being a bright spark at the moment of breaking the circuit.

On account of this spark, a *primary* induction coil is used in low tension or "make and break" ignition systems.

In a single circuit, consisting of a straight wire and a parallel

return wire there is little or no self-induction. When a circuit containing a primary induction coil and a battery is closed there is no spark because at the instant of closing the circuit the current is at rest and on account of self induction *the current cannot at once rise to its full value.*

Mutual Induction.—This is a particular case of electromagnetic induction in which *the magnetic field producing an electric pressure in a circuit is due to the current in a neighboring circuit.*

The effect of mutual induction may be explained with the aid of fig. 336.

If, as illustrated, a circuit including a battery and a switch, be placed near another circuit, formed by connecting the two terminals of a galvanometer by a wire, it will be found that whenever the first circuit 1, is closed by the switch, allowing a current to pass in a given direction, a momentary current will be induced in the second circuit 2, as shown by the galvanometer. A similar result will follow on the opening of the battery circuit, the difference being that the momentary induced current occurring at closure moves in a direction opposite to that in the battery circuit, while the momentary current at opening moves in the same direction.

Currents, besides being induced in circuit 2, at *make* or *break* of circuit 1, are also induced when the current in 1, is fluctuating in intensity.

The most marked results are observed when the make or break is sudden, *the action being strongest at the break of the current in* 1.

The inductive effect of the current in the arrangement shown in figs. 336 and 337 is very weak.

Ques. What name is given to circuit 1?

Ans. The *primary circuit.*

Ques. What name is given to circuit 2?

Ans. The *secondary circuit.*

Ques. What names are given respectively to the currents in circuits 1 and 2?

Ans. The *primary*, and *secondary* or *induced current.*

Primary Induction Coils.—These represent the simplest form of coil, and are used chiefly in low tension ignition to intensify the spark when a battery forms the current source.

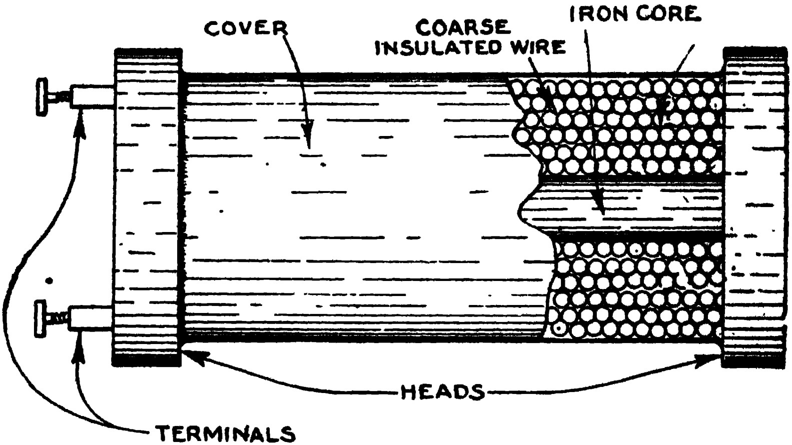


FIG. 338.—Primary induction coil as used for low tension ignition. Coils of this type are made in a great variety of form and size. Ordinarily the winding consists of about six layers of No. 14 copper wire. The winding is usually covered and the ends capped with ebonite so that the core and wires are not exposed.

A ***primary coil*** consists of a *long iron core wound with a considerable length of a low resistance insulated copper wire.*

The length of the core and the number of turns of the insulated wire winding determines the efficiency. The effect of the iron core is to increase the self induction.

The spark produced, as previously explained, is due to self induction, and it should be remembered that in the operation of the coil, the *spark occurs at the instant of* ***breaking the circuit,*** ***not*** *at the instant of* ***making.***

Secondary Induction Coils.—The arrangement shown in

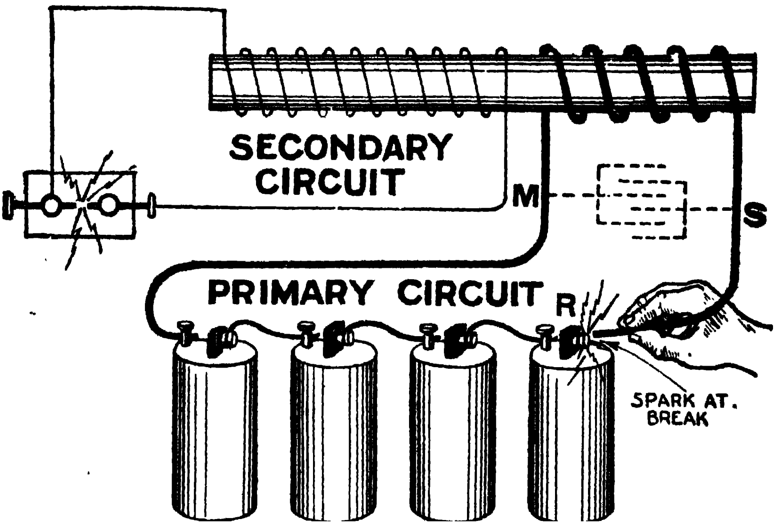


FIG. 339.—Production of spark with plain coil. ***Connect*** the ends or leads of the **secondary** winding to fixed insulators with adjustable spark points so they are from one-sixteenth to one-eighth in. apart. Connect one end of the primary winding to an electric battery, and with the other lead of the primary winding brush against the other terminal of the battery, as indicated. When the contact is broken there will be a spark both at the point of rupture in the primary circuit and at the gap. An electric impulse is also induced in the secondary circuit when the primary circuit is closed and the current flowing in it gradually rises to its maximum value, but this impulse is too feeble to cause a spark to jump across the gap. Only the impulse induced in the secondary during the dying out of the current in the primary is utilized. To avoid a spark at R, on break of primary circuit, place a condenser across this circuit as at M,S, as shown in dotted lines.

fig. 339, may be considered as a very simple or rudimentary form of secondary induction coil.

A ***secondary coil*** consists of a long iron wire core upon which is wound a primary and secondary winding.

In the actual coil, the primary and secondary circuits (corresponding to heavy and fine wire, respectively as shown in

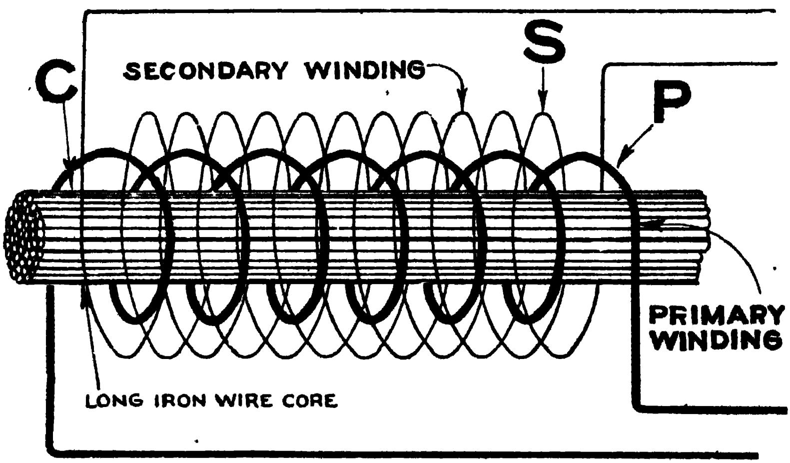


FIG. 340.—Elementary plain secondary coil showing essential parts.

fig. 339) are made up of coils of insulated wire, as shown in fig. 340, the primary coil P, being wound over a core C, and the secondary coil S, being wound over the primary.

The one property of such an arrangement that makes it of great value for most purposes is that *the **voltage** of the induced current may be **increased** or **diminished** to any extent depending*

on the relation between the number of turns in the primary and secondary winding.

This relation may be expressed by the following rule:

The voltage of the secondary current is (approximately) to the voltage of the primary current as the number of turns of the secondary winding is to the number of turns of the primary winding.

For instance, if the voltage of the primary current be 5 volts, the primary winding have 10 turns and the secondary 100 turns, then

Secondary voltage: 5 :: 100 : 10
from which

Secondary voltage = 50 volts (approximately)

The watts in each circuit are approximately the same; hence, if, for instance, the current strength in the primary circuit be 5 amperes, the watts in primary circuit are $5\times5=25$. Accordingly, for the secondary circuit the current strength is:

25 watts ÷ 50 volts = ½ ampere (approximately)

From this, it is seen that where the voltage is raised in the secondary circuit, the current flow is small as compared to that in the primary circuit; therefore, heavy wire is used in the primary winding and fine wire in the secondary, as indicated in figs. 339 and 340.

For most purposes a very much higher secondary voltage is required than in the example just given.

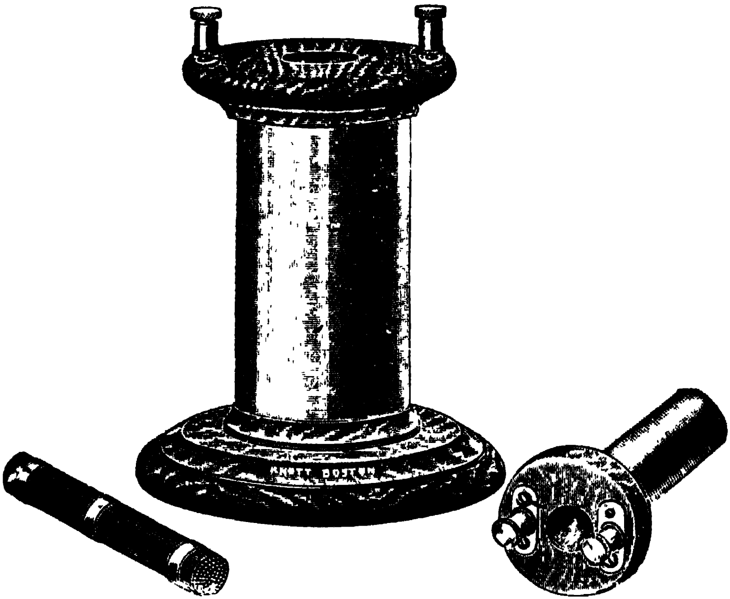
Secondary induction coils may be divided into two general classes:

1. Plain coils;
2. Vibrator and condenser coils.

The plain coil gives but one spark when the primary circuit is made and broken, while the vibrator coil gives a series of sparks following each other in rapid succession.

Plain Secondary Induction Coils.—Coils of this class are very simple and consist of:

1. Core;
2. Primary winding;
3. Secondary winding.



FIGS. 341 to 343.—Knott lecture table primary secondary coil. Primary winding, 6×1¼ ins. few turns of coarse wire; secondary winding, 5×2½ ins large number of turns. Core consists of a bundle of soft iron wires molded by iron bands to form a nearly solid rod.

The construction of a plain coil, such as would be suitable where a strong spark is not required, is about as follows:

The core is made of soft annealed iron wires (No. 20 B and S, gauge) from one-half to three-quarters of an inch in diameter and about six inches

long. Over this core is slipped a spool of insulating material (hard rubber or composition), on which is wound first the primary winding of the coil, which consists of several layers of about No. 18 B and S, gauge silk insulated magnet wire.

After the *primary winding* has been wound over the insulated core, and the ends have been properly brought out through the heads of the spool to be connected to binding posts thereon, a layer of insulating material is applied over the primary wire, and the secondary winding is then wound on.

The wire for the secondary winding consists of about No. 36 B and S, gauge silk covered magnet wire, the amount used varying considerably, depending on the desired voltage of the secondary current.

When all the wire has been wound on, the ends are brought out to the binding posts, the coil is soaked in shellac dissolved in alcohol and baked, or in melted paraffin or a paraffin compound, and allowed to cool. It is then placed in either a cylindrical hard rubber shell or in a hard wood box.

The proportions of such coils vary greatly; for motor cycle use they are made long and of small diameter ($10 \times 2\frac{1}{2}$ inches for instance), while for some other purposes short and thick coils are found more convenient.

Ques. How may the coil just described be connected for demonstrating purposes?

Ans. Connect the ends of the secondary winding to fixed insulators and bend the ends so they are about $\frac{1}{8}$ inch or less apart. Connect one end of the primary winding to a battery and brush the other end of the primary winding against the other terminal of the battery as indicated in fig. 339.

Ques. What happens when the primary circuit is made?

Ans. An electric pressure is induced in the secondary circuit, but of not enough intensity to cause a spark to jump across the air gap.

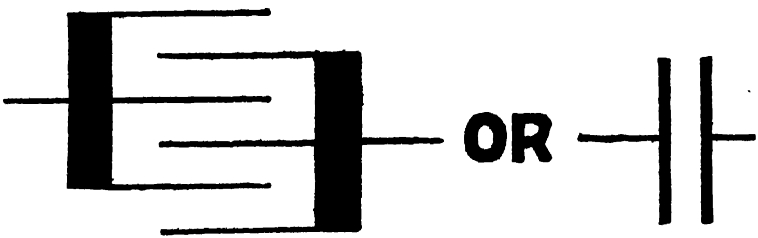
Ques. What happens when the primary circuit is suddenly broken?

Ans. A spark is produced both at the point of break in the primary circuit and at the air gap in the secondary circuit.

Ques. Why is a spark produced at the air gap at break and not at make of the primary current?

Ans. Because when the current is flowing it cannot be stopped instantly on account of self induction, that is, it acts as though it possessed weight.

If the reader have charge of a gas engine with a make and break ignition system, he will often avoid vexatious delays in locating ignition troubles, if he remember that one of the most important conditions for



Figs. 344 and 345.—Conventional diagram of a condenser. *A condenser* is a device designed to absorb or hold an electric charge in about the same manner as a vessel will hold a liquid. Every conductor of electricity forms a condenser and its capacity for holding a charge depends upon the extent of its surface. A condenser is therefore made of conductive material formed into such shape as to present the maximum surface for a given amount of material.

obtaining a good spark is that the *break take place with great rapidity*. This, of course, involves that the ignition spring be adjusted to the proper tension.

Secondary Induction Coils with Vibrator and Condenser.—A plain secondary coil. such as just described, will only give feeble sparks for its size because the inductive effect of the primary winding in the secondary, depends as previously explained, on the rate at which the current in the primary winding decreases or dies out.

If a strong inductive effect is to be produced in the secondary, the current in the primary must stop suddenly.

This is prevented by self induction in the primary winding, which opposes any change in the current strength. The direct result is that, as the primary circuit is broken, a spark appears at the break, which means that the current continues to flow after the break has occurred, dying down comparatively slowly, hence, the inductive effect on the secondary winding is small.

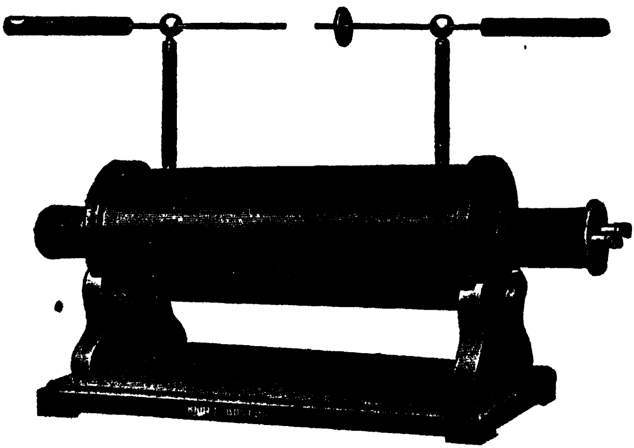


FIG. 346.—Knott liquid interrupting induction coil without interrupter for 110 volt circuit. This coil has been designed to work on the 110 volt circuit and to withstand the entire current from a liquid interrupter, a heavy 7 in. discharge will be found most satisfactory for general work in X-ray and wireless experiments.

The spark at the break in the primary circuit is even larger than that in the secondary circuit, and as this primary spark serves no useful purpose, but, on the contrary, quickly burns away the contact points, such an arrangement is obviously defective.

The vibrator condenser coil is designed to overcome this

trouble and also to give a series of sparks following in rapid succession instead of one.

It should be noted that a series of sparks following each other with considerable rapidity may be obtained with a plain coil by placing a *mechanical vibrator* in the primary circuit, as used on some motor cycle ignition circuits.

The object of the vibrator, of a vibrator condenser coil, is to

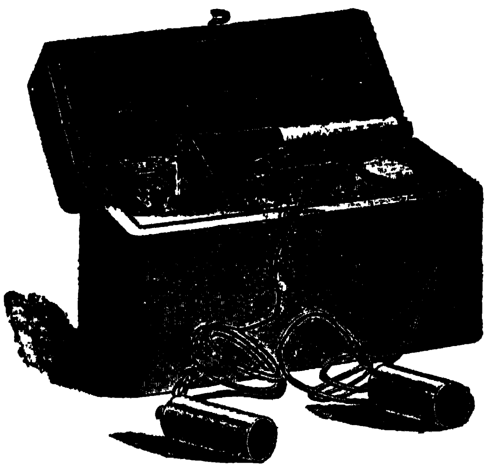


FIG. 347.—A Medical coil with armature and attachments consisting of electrodes, foot place, sponge, induction coil, etc. A current of any degree of intensity may be obtained. The currents furnished are: 1, primary, 2, secondary; and 3, primary and secondary combined.

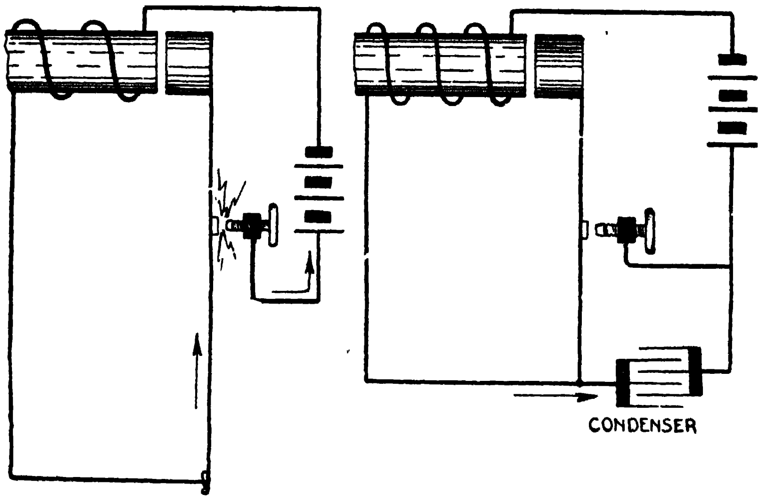
rapidly make and break the primary circuit during the time the primary circuit is closed externally.

It consists of a flat steel spring secured at one end, with the other free to vibrate. At a point about midway between its ends, contact is made with the point of an adjusting screw, from which it springs away and returns in vibrating. The points of contact of blade and screw are tipped

with platinum. One wire of the primary circuit is connected to the blade and the other to the screw, hence, the circuit is made when the blade is in contact with the screw and broken when it springs away.

A condenser is used to absorb the self-induced current of the primary winding and thus prevent it opposing the rapid fall of the primary current.

Every conductor of electricity forms a condenser and its capacity for absorbing a charge depends upon the extent of its surface. Hence, a con-



FIGS. 348 and 349.—Detail of vibrator showing condenser connection and how it prevents arcing at the break in the primary current.

denser is constructed of conductive material so arranged as to present the greatest surface for a given amount of material.

The usual form of condenser for induction coils is composed of a number of layers of tin foil separated by paraffin paper, each alternate layer being connected at the ends.

The symbols for a condenser in wiring diagrams are shown in figs. 344 and 345

Fig. 351 is a diagram of a vibrator coil. C, represents the core composed of soft iron wires. P, is the primary winding and S, the secondary. There is no connection between these windings and they are carefully insulated. Y, is the vibrator and D, the center about which it vibrates. W, is a switch used for opening and closing the primary circuit; B, a battery of several cells (four to six for ignition coils). The point of adjusting screw A, rests against a platinum point R, soldered upon the vibrator.

If the switch W, be closed, the electric current generated by the battery B, will flow through the primary winding. This will cause the core C, to become magnetized, and the vibrator Y, will at once be drawn toward it. This will break the connection at R. The core, being made

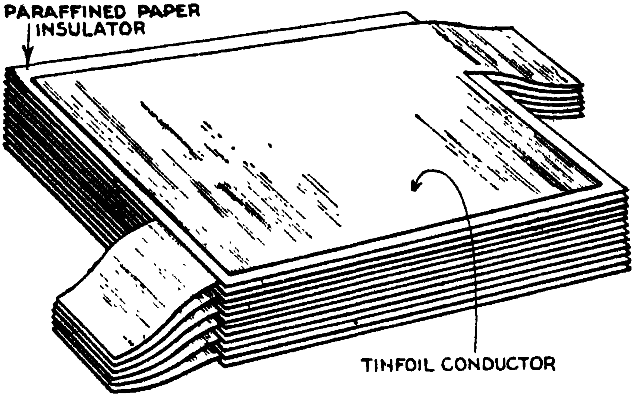


FIG. 350—Construction of condenser for an induction coil. The conducting material used is tinfoil, of which a large number of sheets are prepared, all cut to the same size. These are placed, one on top of the other, like the pages of a book, with a thin layer of insulating material between, usually two sheets of paraffined paper. Numbering the successive sheets of tinfoil serially, all sheets of even number are connected together and all sheets of odd number are connected together, these connections forming the terminals of the condenser. The condenser is then connected across the break in the primary circuit.

of soft iron, immediately upon the interruption of the current, will again lose its magnetism, and the vibrator will return to its original position. This again closes the circuit, after which the operation of opening and closing it is repeated with great rapidity so long as the switch W, remains closed.

The cycle of actions may be briefly stated as follows:

1. A primary current flows and magnetizes the core;

2. The magnetized core attracts the vibrator which breaks the primary circuit;

3. The core loses its magnetism and the vibrator springs back to its original position;

4. The vibrator, by returning to its original position, closes the primary circuit and the cycle begins again.

Magnetic Vibrators.—Many types of vibrator are used on

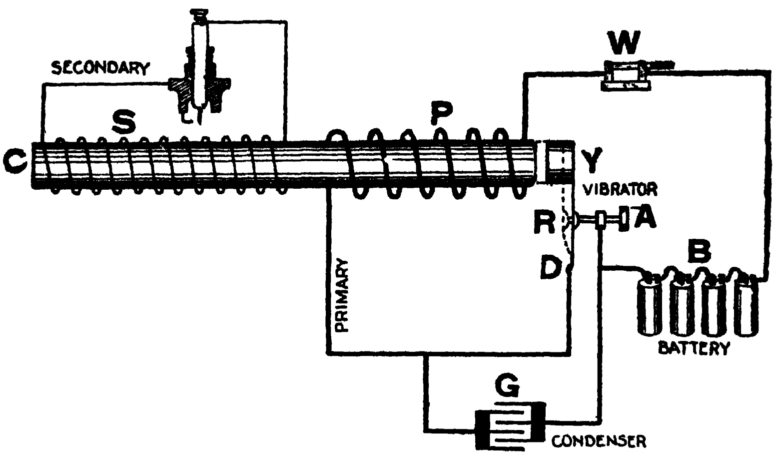


FIG. 351.—Diagram of a vibrator coil. The parts are as follows: A, contact screw; B, battery; C, core; D, vibrator terminal; G, condenser; P, primary winding; S, secondary winding; W, switch; Y, vibrator. When the switch is closed, the following cycle of actions take place: 1, the primary current flows and magnetizes core; 2, magnetized core attracts the vibrator and breaks primary circuit; 3, the magnetism vanishes, including a momentary high tension current in the secondary winding; 4, magnetic attraction of the core having ceased, vibrator spring renews contact; 5, primary circuit is again completed and the cycle begins anew.

induction coils, the most important requirement being that *the break occur with great rapidity.* In order to render the break as sudden as possible, different expedients have been resorted to, all tending to make the mechanism more complicated, yet having sufficient merit in some cases to warrant their adoption.

In the plain vibrator, the circuit is broken at the instant the spring begins to move, hence, the operation must be comparatively slow.

In order to render the break more abrupt some vibrators have two moving parts, one of which is attracted by the magnetic core of the coil and moved a certain distance before the break is effected. A vibrator of this type is shown in fig. 352 and described under the illustration.

Vibrator Adjustment.—When a vibrator coil is used, the

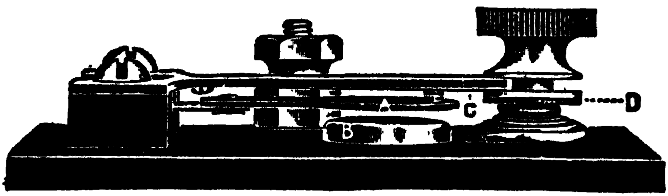


FIG. 352.—A hammer vibrator. When at rest, the upward tension of the spring, which carries the armature A, holds the platinum points in contact and causes the upper spring C, to leave shoulder of adjusting screw D, and rest against the heavy brass plate above it. When the iron core B, attracts the armature A, the downward tension on the upper spring C causes the latter to follow the armature down, holding the platinum point in contact, until the end of the upper spring C, strikes the lower shoulder of the adjusting screw D, which gives it a "hammer break." The adjusting screw is held firmly in position by a bronze spiral spring under shoulder D.

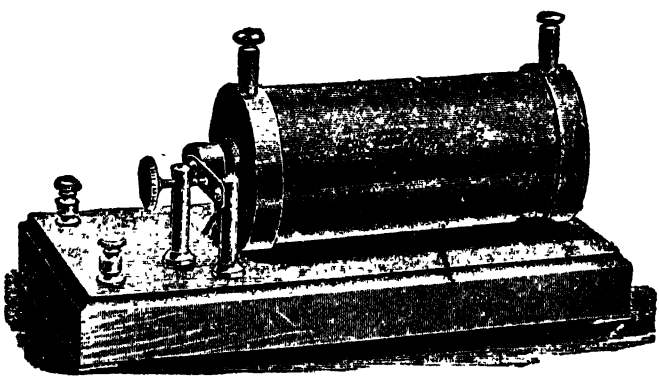


FIG. 353.—Rhumkorff induction coil. *A secondary coil* with vibrator and condenser; a type generally used in the laboratory. The name Rhumkorff was formerly very widely applied to induction coils for the reason that some of the earliest coils were constructed by Rhumkorff.

quality of the spark depends largely upon the proper adjustment of the vibrator.

The following general instructions for adjusting a plain vibrator should be carefully noted:

1. Remove entirely the contact adjusting screw.
2. See that the surfaces of the contact points are flat, clean and bright.

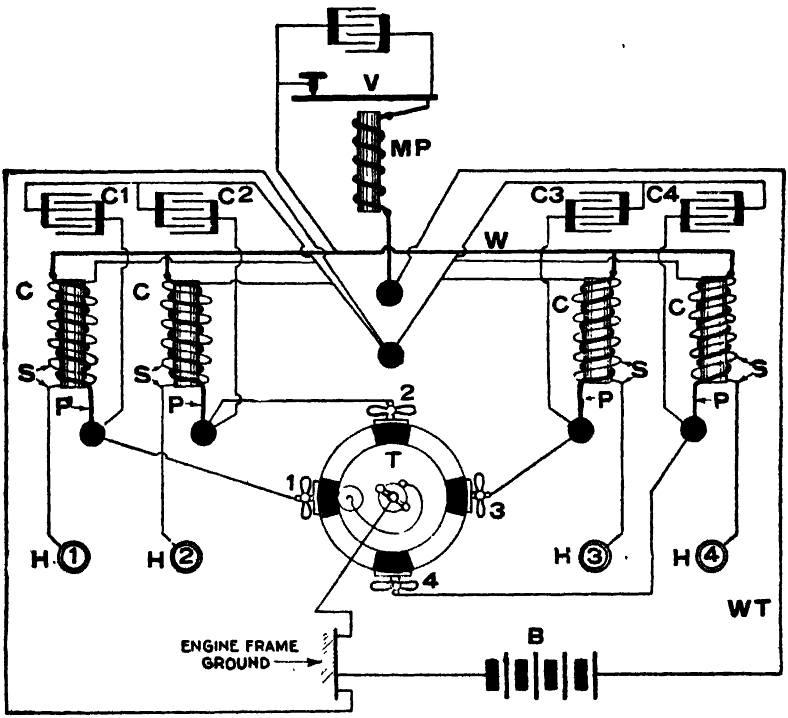


FIG. 354.—Circuit diagram of a master vibrator coil. B, is the battery; C, the unit coils; C1, C2, etc., the condensers; P, the primary windings and S, the secondary windings, H1, H2, etc., the spark plugs; T, the timer; MP, the master primary; V, the vibrator; W, the common primary connection; 1, 2, etc the stationary contact of the timer.

3. Adjust the vibrator spring so that the hammer or piece of iron on the end of the vibrator spring stands normally about one-sixteenth of an inch from the end of the coil.
4. Adjust the contact screw until it just touches the platinum contact on the vibrator spring—be sure that it touches, but very lightly. Now start the engine; if it miss at all, tighten up, or screw in the contact screw a trifle further—just a trifle at a time, until the engine will run without missing explosions.

Table of Induction Coil Dimensions

Length of spark......	1/4 inch	1/2 inch	1 inch	2 inches
Size of bobbin ends...	2 1/4×1 1/4	2 1/2×5/16	3×3/4	4×2 3/4×3/4
Length of bobbin.....	4	5 1/2	6 1/2	6 1/2
Length and diameter of core............	4 1/4×7/16	6×5/8	6 1/2×3/4	—
Size of base..........	7 1/4×3 1/4×1 1/2	9×5×2	14 1/2×6×1 1/4	12×7 1/2×3 1/2
Size of tinfoil sheets...	4×2	5 1/2×3 1/4	6×4	6×6
Number of tinfoil sheets.............	36	40	40	60
Size of paper sheets...	5×3	6 1/2×4 1/4	9×5	—
Primary coil.........	No. 18	No. 18	2 layers No. 16, silk covered.	2 layers 14B. W. G. silk covered.
Secondary coil.......	1/4 lb. No. 40	1 lb. No. 40	1 1/4 lbs. No. 38	2 1/2 lbs. No. 36.

Table of Sparking Distances in Air*

Volts.	Distance. (Inches.)	Volts.	Distance. (Inches.)
5000...................	.225	60000..................	4.65
10000..................	.47	70000..................	4.85
20000..................	1.00	80000..................	7.1
30000..................	1.625	100000.................	9.6
35000..................	2.00	130000.................	12.95
45000..................	2.95	150000.................	15.00

*NOTE —These values are correct for effective sinusoidal voltages.

Points Relating to Ignition Coils.—1. Most ignition induction coils or "spark coils" as they are called, have terminals marked "battery," "ground," etc., and to short circuit the timer for the purpose of testing the vibrator, it is only necessary to bridge with a screw driver from the "battery" binding post to the "ground" binding post.

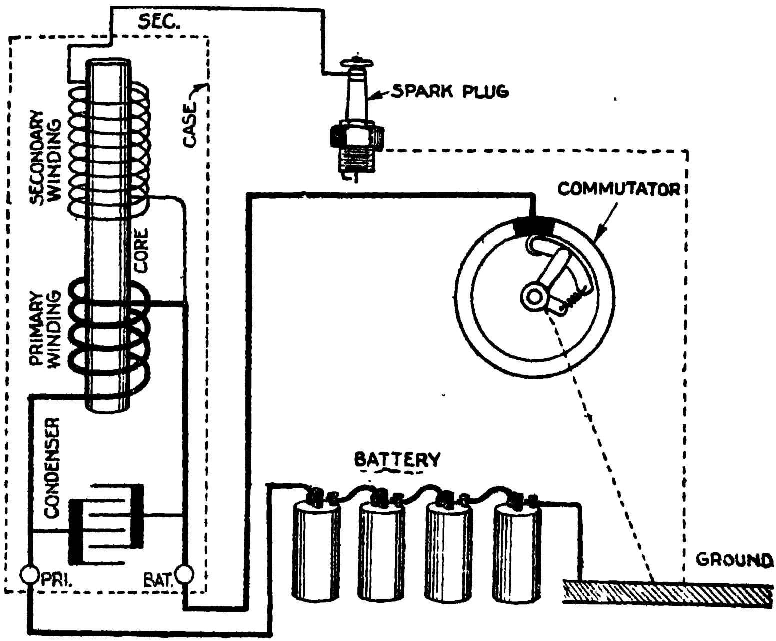


FIG. 355 —Diagram of battery and coil connections for jump spark ignition as applied to a motor cycle. Coils are usually plainly labeled with the abbreviations: "Bat.," "Ground" or "Pri.," "Sec.," in heating that the wires are to be connected to the battery, the primary circuit or contact maker, and the spark plug. The battery and primary wires being for the low tension circuit are easily distinguished from the secondary wire by the small amount of insulation surrounding them.

2. In adjusting the vibrator of an ignition coil, the latter should not require over one-half ampere of current.

3. A half turn of the adjusting screw on a coil will often increase the strength of the current four or five times the original amount, hence, the necessity of carefully adjusting the vibrator. When the adjustment is not properly made it causes, 1, short life of the battery, 2, burned contact points, and 3, poor running of the engine.

4. In adjusting a multi-unit coil, if any misfiring be noticed, hold down one vibrator after another until the faulty one is located, then screw in its contact screw very slightly.

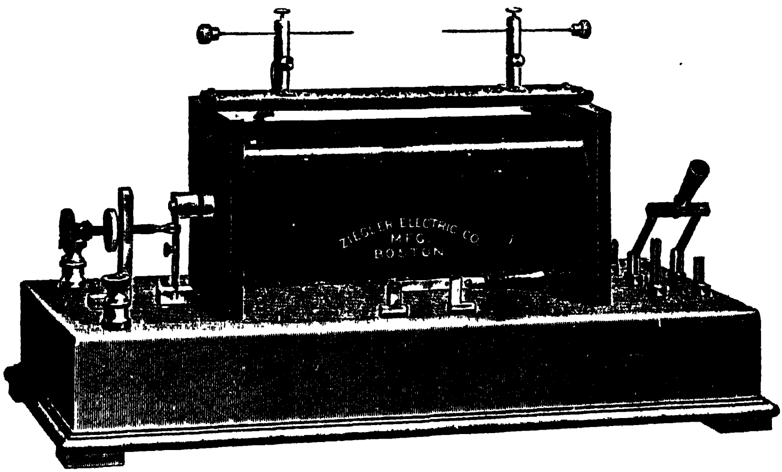
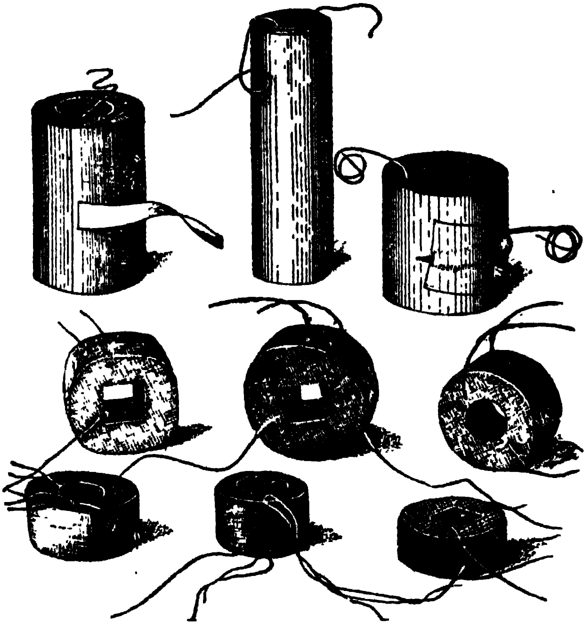


FIG. 356.—Ziegler vibrator induction coil designed for heavy discharge rather than length of spark. This is obtained by use of exceptionally heavy primaries in conjunction with extra insulation.

5. The number of cells in the circuit should be proportioned to the design of the coil.

If the coil be described by the maker as a 4 volt coil, it should be worked by two cells of a storage battery or four dry cells. The voltage of the latter will be somewhat higher, but since their internal resistance is also greater, the current delivery will be about the same. Most coils are made to operate on from 4 to 6 volts.

6. It is a mistake to use a higher voltage than that for which the coil is designed, because it does not improve the spark and the contact points of the vibrator will be burned more rapidly, moreover, the life of the battery will be shortened.



FIGS. 357 to 359.—Acme ignition coils. These coils are wound with paper between layers of enameled wire and with flexible terminal wires attached. If so specified, they are impregnated under vacuum and finally tested to meet all requirements.

FIGS. 360 to 365.—Acme Transformer coils. Audio frequency transformers are generally admitted to be the best amplifiers yet developed for radio circuits. Much has been done in a short time to bring transformer amplification to a high degree of perfection. Experience has shown that windings for these transformers must be wound with accuracy.

NOTE.—*An increasing number* of manufacturers of electrical apparatus are purchasing their wire, tape, sleeving, etc. in the form of finished windings. By doing this they get the advantage of the low costs of a concern which specializes in winding, saving the expense of putting the raw materials into packages suitable for the market, not to mention the smaller items of transportation charges on reels and spools and the cost of those which are broken or lost. To concerns whose business is seasonal, the purchase of finished windings is of particular advantage, as it saves the interest charges on an investment which is idle, a large part of the time, as well as the expense involved in periodic training of a force of operators.

Cost Factors in Coil Design.—In cases where low initial cost is an object, the designer should consider the following points which bear upon the economical productions of coils in large quantities.

1. Wherever possible plenty of room should be allowed for the coil. With engineers who are unfamiliar with the necessary allowances required in quantity production, there is a tendency to crowd the winding into such a small space that considerable difficulty is experienced in getting the number of turns, or specified resistance within the dimensional limits. This, of course, results in an increase in the cost of winding.

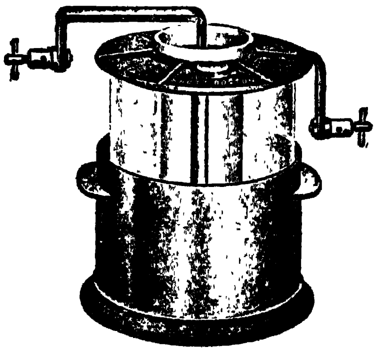


FIG. 366.—Knott electrolytic interrupter for coils from 4 to 6 in. spark discharge. Electrolytic breaks have been expensive and often a failure by reason of the difficulty in adjusting the size of the gas tube to the line voltage and the amperage which is to be drawn from the break. *In construction,* the interrupter contains a porcelain cylinder in which the size of the opening is carefully adjusted to the amperage of the current to be drawn. This cylinder is carried on a lead shelf, being part of the inner lead cylinder. The terminals are carried well out on the ends of long lead bars as shown in the illustration. The acid jar is placed in an iron receptacle which acts as a radiator and serves to retain the acid in case the acid jar is accidentally broken.

2. Where design conditions permit, a round coil should be adopted. Square and rectangular shapes require winding at lower speeds and a correspondingly increased cost. This is especially true of bobbin or form wound coils.

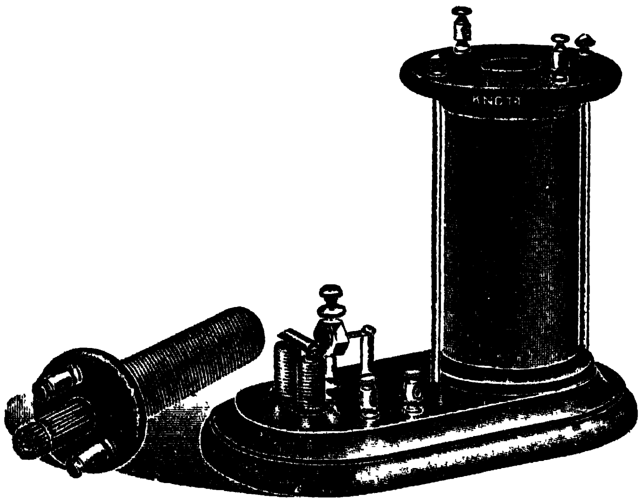
3. Enameled wire is gradually replacing textile covered wires for most magnet windings and invariably results in a saving.

4. The additional cost of equipping a coil with flexible leads is an item sometimes not fully appreciated. While windings of wire, sizes from No. 30

to 44, should have flexible leads, coils wound with larger sizes can often be used as effectively with leads of winding wire itself.

5. Wherever the operation of a direct current coil is not materially affected by a variation of from 10% to 20% in strength, a slight saving can be effected by winding to a given number of turns instead of a specified resistance.

Coil Winding Calculations.—The following formulæ are being given without the usual individual illustrations, the re-



Figs. 367 and 368.—Knott lecture table secondary vibrator induction coil showing removable core and primary winding. The secondary winding is mounted on a polished hardwood base connected in series with a simple electro-magnetic vibrator added to give positive uniform "make and break" in the circuit. Demonstrates a simple induction coil without condenser.

lations being sufficiently clear to those requiring their use. It should be noted that it is impossible to accurately state the value of turns per sq. in. ohms per cu. in., etc. These values are dependent upon winding conditions, and will therefore, vary considerably between different types of machines, and

even between different sizes of coils. The tables as given are average values and results derived therefrom do not under ordinary conditions vary more than 5% either way. All resistance data is based on 68° F. or 20° C.

Referring to fig. 369, the following is the notation:

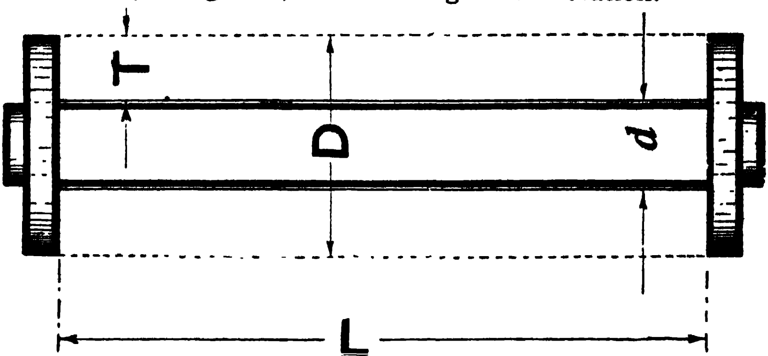


FIG. 369.—Diagram of coil to accompany coil winding calculations.

L = Length of winding space
D = Outside diameter of winding
d = Diameter of insulated core
M = Mean diameter
T = Thickness of winding
V = Winding volume
R = Total resistance
r = Resistance per cu. in. (Table B)
s = Resistance per lineal in. (Table A)
p = Resistance per lb.
N = Total number of turns
n = Turns per sq. in. (Table D)
W = Total weight of insulated wire
w = Weight per cu. in. (Table E)
m = Weight per 1000 ft. (Table F)

Resistance Per Inch

Table A

B. & S.	OHMS	B. & S.	OHMS	B. & S.	OHMS
8	.0000552	19	.0006698	30	.008583
9	.0000659	20	.0008450	31	.01082
10	.0000831	21	.001065	32	.01365
11	.0001047	22	.001343	33	.01722
12	.0001322	23	.001693	34	.02171
13	.0001666	24	.002136	35	.02736
14	.0002101	25	.002692	36	.03452
15	.0002649	26	.003396	37	.04352
16	.0003341	27	.004281	38	.05487
17	.0004212	28	.005399	39	.06920
18	.0005312	29	.006809	40	.08725

Formulæ showing the relations between above factors.

$$T = \frac{D-d}{2}$$

$$R = Vr = \pi MLTr = \pi MNs = Wp$$

$$M = \frac{D+d}{2} = T+d \qquad N = LTn = \frac{R}{\pi Ms}$$

$$D = \sqrt{\frac{4V+\pi Ld^2}{\pi L}} \qquad W = \frac{R}{p} = Vw = \pi MLTw = \frac{\pi MNm}{12{,}000}$$

$$V = \pi MLT = \frac{\pi L(D^2-d^2)}{4} = \frac{R}{r} = \frac{W}{w}$$

To find size of wire, take the size having in the following tables a value nearest corresponding to that determined by either of the following formulæ:

$$r = \frac{R}{V} \qquad n = \frac{N}{LT}$$

The following examples show the easiest method of working out the three principal forms of coil winding problems:

Example.—Given bobbin and wire—to find the winding data.

$L = 4''$ $\quad D = 4''$ $\quad d = 1\frac{1}{8}''$ $\quad$ No. 24 Enamel.

Given:

$D = 4$
$d = 1.125$ subtracting
$2)2.875$ dividing
$T = 1.438$ $\quad \left(\frac{D-d}{2}\right)$
$d = 1.125$ adding
$M = 2.563$ $\quad (T+d)$
$\pi M = 3.1416 \times 2.563$
$= 8.038$
$V = 8.038 \times 4 \times 1.438$
$= 46.23$ cu. in. (πMLT)

$R = 46.23 \times 4.488$ $\quad$ (Vr)
$= 207.4$ ohms.
$N = 4 \times 1.438 \times 2{,}100$ $\quad$ (LTn)
$= 12{,}090$ $\quad \left(\frac{R}{\pi Ms}\right)$
Also $N = 207.4 \div (8.038 \times .002136)$
$= 12{,}060$ turns
$W = 46.23 \times .2178$ $\quad$ (Vw)
$= 10.07$ lb.
Also $W = 207.4 \div 20.60$ $\quad \left(\frac{R}{P}\right)$
$= 10.07$ lb.

Example.—Given bobbin, resistance and insulation of wire—to find size of wire.

Given: $L = 2\frac{3}{4}''$ $D = 1\frac{1}{2}''$ $d = \frac{1}{2}''$ 400 ohms. Silk enamel

By the above method:
$V = 8.635$ cu. in.

$r = 400 \div 8.635$
$= 46.29$ ohms. $\left(\frac{R}{V}\right)$

Table B indicates No. 30 Silk enamel as being nearest in value to that required.

Example.—Given winding length and diameter of insulated core, resistance and wire—to find the number of turns.

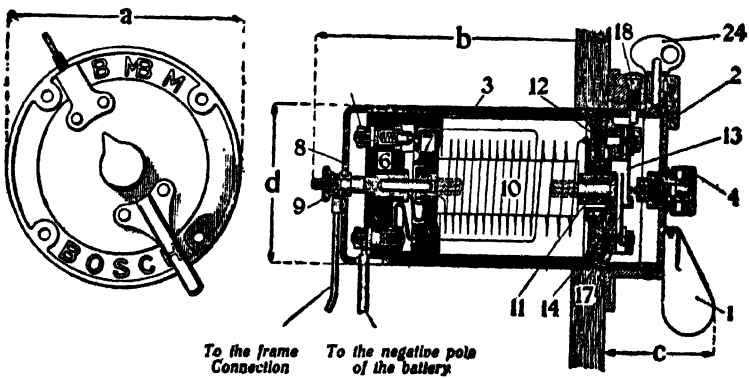
Given: $L = 2$ $d = .4''$ $R = 125$ ohms. No. 30 S. S.

$V = 125 \div 58.45$
$= 2.140$ cu. in. $\left(\frac{R}{r}\right)$

Then by the first method:

$$D = \sqrt{\frac{(4 \times 2.140) + (3.1416 \times 2 \times .4^2)}{3.1416 \times 2}}$$
$= 1.235''$

$T = .4175$
$N = 2 \times .4175 \times 6810$ (LTn)
$= 5{,}693$ turns



FIGS. 370 and 371.—Bosch type C horizontal secondary coil. ***The parts are:*** 1, switch handle; 2, movable cover; 3, coil housing; 4, starting press button; 6, fixed connection plate; 7, movable switch plate; 8, cable cover; 9, milled edge nut; 10, iron core; 11, plate carrying the starting arrangement and the condenser; 12, condenser; 13, contact spring; 14, vibrator; 15-16, auxiliary contact breaker; 17, vibrator spring; 18, stop screw for switch handle; 24, locking key.

NOTE.—The accompanying calculations and tables are furnished by Belden Mfg. Co.

Ohms Per Cubic Inch

Table B

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	.00315	.00293	.00265	....	....	.00287	....
9	.00475	00435	.00368	....	....	.00422	....
10	.00748	00698	00631	....	....	00664	....
11	.01183	.01088	.00974	....	....	.01047	....
12	.01878	.01718	.01519	....	....	.01651	....
13	.0295	0266	0233	....	....	0251	....
14	.0464	.0416	.0359	....	....	0393	....
15	0734	0650	.0551	....	....	0609	....
16	.1162	1042	.0869	.1172	1092	0966	.1089
17	.1840	.1613	1331	.1840	.1705	1508	.1718
18	2910	.2508	.2008	2910	.2672	.2326	.2682
19	.4560	.3890	.3048	.4565	.4145	.3560	.4165
20	.7200	.6008	.4605	7165	.6430	.5440	.6500
21	1.134	.9240	6920	1 123	9960	.8310	1.007
22	1.800	1.515	1 162	1 766	1 545	1 354	1.578
23	2 820	2 320	1 744	2 743	2 370	2 066	2 438
24	4 488	3 557	2 596	4 293	3.642	3 150	3.790
25	7.080	5 440	3 822	6 645	5 570	4 820	5 867
26	11.27	8 300	5 740	10 05	8 510	7 318	9 100
27	17 75	12 52	8 330	15 75	12 89	[illegible] 08	13 92
28	28.34	18 90	12.15	24 83	19 54	16 74	21 75
29	44.32	28 05	17.30	37 65	29 08	24 91	33 12
30	70 15	42 08	25.15	58 45	43 75	37.08	50.56
31	110.4	62 45	36 05	89 40	65 08	55 40	77 60
32	172.6	91 45	50.76	134 7	95 40	81 35	116.8
33	279 0	134 0	71 30	208 0	140 5	120 8	179 1
34	433.2	195.6	99 77	309 5	205 8	175.	265.
35	684.5	281 8	138.7	459 6	297 3	251.7	396.7
36	1094.	405.7	191.6	685 6	429.	364 2	597 3
37	1723.	576 7	268.	1014.	613.5	522.	887.5
38	2693.	817.7	357.	1497.	875.8	735 5	1294.
39	4332.	1148.	480.	2193.	1235.	1048.	1927.
40	6770.	1605.	680.	3202.	1736.	1461.	2791.

Ohms Per Pound

Table C

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	0124	.0124	.0123	....	....	.0122	....
9	.0197	0197	.0197	....	....	.0194	....
10	.0314	0313	.0310	....	....	0310	....
11	.0497	0498	.0492	....	....	.0488	....
12	.0791	.0788	.0778	....	....	0773	....
13	1255	.1250	.1232	....	....	.1227	....
14	.2005	.1960	.1952	....	....	1958	....
15	.3180	3150	.3080	....	....	3100	....
16	5050	4990	4885	.5080	5040	.4890	.5000
17	8051	.7900	.7730	8075	.8005	7785	.7960
18	1 278	1 253	1 218	1.283	1 270	1 250	1.292
19	2.032	1 990	1 915	2 038	2.015	1 950	2 002
20	3 239	3 145	3 050	3.235	3 190	3 100	3.183
21	5 138	4 980	4 760	5 140	5 070	4 870	5 030
22	8 186	7 865	7 435	8 150	8 035	7 720	8.000
23	12 97	12 41	11 78	12 94	12 75	12 16	12 63
24	20 60	19 63	18 35	20 58	20 13	19.20	20 00
25	32 70	31.10	28 60	32 58	31.75	30 15	31 72
26	51 95	48 90	44 50	51 50	50 25	47 60	50.30
27	82 55	77 15	68 00	81.75	79.60	74.90	79 60
28	131 2	121 5	106 5	129 6	125.9	118 2	126.1
29	208 7	192 0	167.	205 8	198 0	187 0	198.8
30	331 5	303 0	260 5	326 0	310 0	289.5	312 2
31	526 5	471 0	400 0	517 0	486 0	451.5	493.0
32	836 5	736 0	607 5	816 0	758.5	699.8	476 0
33	1332	1135	910 0	1280	1180.	1085.	1227.
34	2118	1762.	1351	2020	1850.	1680.	1931.
35	3332.	2730.	2050.	3175.	2905.	2550.	3030.
36	5340	4170	3040.	5035.	4500.	3907	4735.
37	8480.	6360	4340.	7885.	7050.	5750.	7420.
38	13490.	9400	6290.	12350.	10780.	8465.	11520.
39	21450.	13800.	8875.	19550	16500.	12370.	18000.
40	34100	20150.	12800.	31500.	24500.	18350.	27810.

Turns Per Square Inch

Table D

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Col-enamel	Silk enamel
8	57	53	48	...	...	52	...
9	72	66	59	...	...	64	...
10	90	84	76	...	...	80	...
11	113	104	93	...	...	100	...
12	141	129	114	...	...	124	...
13	177	160	140	...	...	151	...
14	221	198	171	...	...	187	...
15	277	245	208	...	...	230	...
16	348	312	260	351	327	289	326
17	437	383	316	437	405	358	408
18	548	472	378	548	503	438	505
19	681	581	455	682	619	532	622
20	852	712	545	848	761	644	769
21	1065	868	650	1055	935	780	946
22	1340	1128	865	1315	1150	1008	1175
23	1665	1370	1030	1620	1400	1220	1440
24	2100	1665	1215	2010	1705	1475	1775
25	2630	2020	1420	2470	2070	1790	2180
26	3320	2443	1690	3005	2510	2155	2680
27	4145	2925	1945	3680	3010	2590	3275
28	5250	3500	2250	4600	3620	3100	4010
29	6510	4120	2560	5530	4270	3660	4865
30	8175	4900	2930	6810	5100	4320	5890
31	10200	5770	3330	8260	6010	5120	7170
32	12650	6700	3720	9870	6990	5960	8560
33	16200	7780	4140	11850	8160	7020	10400
34	19950	9010	4595	14250	9480	8060	12200
35	25000	10300	5070	16800	10870	9200	14500
36	31700	11750	5550	19850	12430	10550	17300
37	39600	13250	6045	23300	14100	12000	20400
38	49100	14900	6510	27300	15960	13400	23600
39	63600	16600	6935	31700	17850	15150	27850
40	77600	18400	7450	36700	19900	16750	32000

Pounds Per Cubic Inch

Table E

B & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Col-enamel	Silk-enamel
8	2540	2362	2154	...	...	2352	...
9	2411	2208	1969	...	...	2175	...
10	2382	2230	2036	...	...	2142	...
11	2381	2185	1980	...	...	2145	...
12	2374	2180	1953	...	...	2131	...
13	2350	2128	1891	...	...	2045	...
14	2314	2122	1838	...	...	.2007	...
15	2308	2063	1789	...	...	1964	...
16	2301	2089	1777	2318	2150	1975	2178
17	2287	2042	1722	.2279	2130	.1937	2158
18	2277	2001	1648	.2268	2103	1860	2075
19	2262	1955	1592	2240	2058	1826	2062
20	2224	1912	1510	2215	.2015	1754	2041
21	2208	1856	1454	2186	1965	1706	2002
22	2198	1926	1563	2167	1923	1754	1973
23	2173	1869	1481	.2121	.1858	1712	.1930
24	2178	1810	1414	2116	1814	1641	1896
25	2165	1748	.1337	2040	.1754	1598	.1849
26	2170	1697	.1290	1952	.1693	.1537	1810
27	2151	1624	.1225	1927	1619	1479	1749
28	2160	1556	1141	.1915	.1552	1416	.1725
29	2128	1461	.1036	.1830	.1468	.1332	.1666
30	2121	1388	0966	1793	1411	.1281	.1619
31	2097	1326	0901	.1729	.1341	1227	1574
32	2064	1244	.0836	.1651	.1257	1162	1505
33	2094	1181	0784	1625	.1191	1113	1458
34	2045	1111	0738	.1532	.1112	.1042	.1372
35	2041	1032	.0677	1447	1023	0987	1313
36	2049	0973	0630	.1361	0954	.0933	.1256
37	2032	0907	.0606	.1286	.0870	.0908	.1196
38	1996	.0870	0564	.1212	.0812	.0869	.1123
39	.2019	0832	0541	1132	.0749	.0847	.1070
40	.1985	.0797	.0530	.1017	.0712	.0796	.1003

Weight Per 1000 Feet in Pounds

Table F

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	50 55	50 60	51 15	......	...	51 25	....
9	40 15	40 15	40 60	....	....	40 70	.....
10	31 80	31 85	32 18	.....	.	32 26	.....
11	25 25	25 30	25 60	......	.....	25 66	....
12	20 05	20 10	20 40	......	......	20 48	..
13	15 90	15 99	16.20	.....	..	16 32	......
14	12 60	12 73	12 91	.....	......	12 90	....
15	10 00	10 10	10 33	.....	.	10 27	..
16	7.930	8 025	8 210	7 890	7 955	8 180	8 010
17	6 275	6 395	6 540	6 260	6 315	6 480	6 340
18	4 980	5 080	5 235	4 970	5 015	5 160	5 040
19	3 955	4 035	4 220	3 940	3 990	4 120	4 010
20	3 135	3 218	3 373	3 132	3 173	3 275	3 190
21	2 490	2 561	2 685	2 488	2 520	2 625	2 545
22	1 970	2 048	2 168	1 976	2 006	2 118	2 045
23	1 565	1 635	1 727	1 570	1 593	1 668	1 608
24	1 245	1 304	1 398	1 247	1 272	1 335	1 283
25	988	1 039	1 129	994	1 018	1 071	1 018
26	7845	8335	9140	7905	8100	8570	8100
27	.6220	6660	7560	.6280	6450	6845	6445
28	4940	5325	6075	4980	5140	5480	5140
29	.3915	4255	4890	3970	4130	4375	4120
30	.3105	3400	3955	3160	3330	3555	3295
31	2465	2762	3257	2517	2678	2874	2635
32	1960	2230	2700	2100	2170	2348	2115
33	.1550	1816	2270	.1611	1750	1904	1683
34	1230	1478	1928	1290	1412	1551	1348
35	0980	1202	1600	1035	1130	1286	1085
36	.0776	0994	1361	.0823	0920	1062	0872
37	0616	0822	1204	0663	0740	0908	0704
38	.0488	0702	1049	0534	0623	0778	.0572
39	.0387	.0602	0937	0424	0505	0669	0463
40	0307	.0519	0838	0345	0429.	0571	0376

Outside Diameters*

Table G

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	1306	1355	.1415	......	......	.1376	....
9	.1165	1214	.1274	......	......	1235	......
10	1040	1079	1129	....	....	.1100	......
11	0927	0967	.1017	.....	.....	0987	.....
12	0828	0868	0918	......	.....	0888	......
13	0740	0780	0830	.....	......	0800	.....
14	0661	0701	0751	....	......	.0721	....
15	0591	0631	0681	.....	....	0651	....
16	0528	0558	0608	.0528	0546	0578	.0548
17	0470	0503	0553	.0473	0491	0520	.0490
18	0421	0453	0503	.0423	0441	0471	.0441
19	0377	0409	0459	0379	0397	0427	0397
20	0337	0370	0420	0340	0358	0387	.0357
21	0302	0335	0385	0305	0323	0352	0322
22	0269	0293	.0333	0273	0291	0309	0289
23	0241	0266	0306	0246	0264	0281	0261
24	0215	0241	0281	0221	0239	0255	0235
25	0192	0219	0259	0199	0217	0232	0212
26	0171	0199	0239	0179	0197	0211	.0191
27	0153	0182	0222	0162	0180	0193	0173
28	0136	0166	0206	0146	0164	0176	.0156
29	0122	0153	0193	0133	0151	.0162	0142
30	0109	0140	0180	0120	0138	.0149	.0129
31	0097	0129	.0169	0109	0127	0137	0117
32	0087	01195	01595	00995	.01175	0127	0107
33	0077	01108	.01508	00908	01088	0117	.0097
34	0069	.01030	01430	00830	01010	0109	.0089
35	0062	00961	01361	00761	.00941	0102	0082
36	0055	00900	01300	00700	00880	0095	0075
37	0049	00845	01245	.00645	00825	.0089	.0069
38	0044	.00796	01196	00596	00776	.0084	.0064
39	0039	00753	01153	00553	.00733	.0079	.0059
40	.0035	00714	01114	00514	.00694	.0075	.0055

*These figures in process of revision at time of printing.

TEST QUESTIONS

1. *What is an induction coil?*
2. *Name some uses for induction coils.*
3. *What are the two general classes of coils?*
4. *Upon what does the action of each class depend?*
5. *Define self induction.*
6. *What other name is sometimes given to self induction?*
7. *What is self induction due to and under what conditions does it become especially marked?*
8. *How does self induction manifest itself?*
9. *What important use should be made of self induction?*
10. *What kind of a circuit contains little or no self induction?*
11. *What is mutual induction, and what important uses are made of same?*
12. *Describe in detail the effect of mutual induction.*
13. *When is the action of mutual induction strongest?*
14. *What is a primary induction coil, and what important use is made of same?*
15. *In the operation of a primary induction coil when does the spark occur?*
16. *Describe the essential features of a secondary induction coil.*
17. *What property of the secondary induction coil makes it of great value for most purposes?*
18. *Upon what does the induced voltage depend, and what is the rule?*
19. *Name three classes of secondary induction coils.*
20. *How many sparks does a plain coil give when the main circuit is made and broken?*
21. *Describe the construction and operation of a plain secondary coil.*
22. *Why is the spark produced at "break" and not at "make"?*
23. *Why is a condenser used with a secondary coil?*
24. *Describe the construction and operation of a secondary coil with vibrator and condenser.*
25. *What is the usual form of condenser used with coil?*
26. *State the cycle of operation of a vibrator coil.*
27. *What is a magnetic vibrator?*
28. *Give instructions for vibrator adjustment*
29. *Mention some points relating to ignition coils.*
30. *How is a coil winding calculated? give examples.*
31. *Describe a few experiments with an induction coil.*

CHAPTER 12

The Dynamo

The dynamo is *a machine which converts mechanical energy into electrical energy by electro-magnetic induction.*

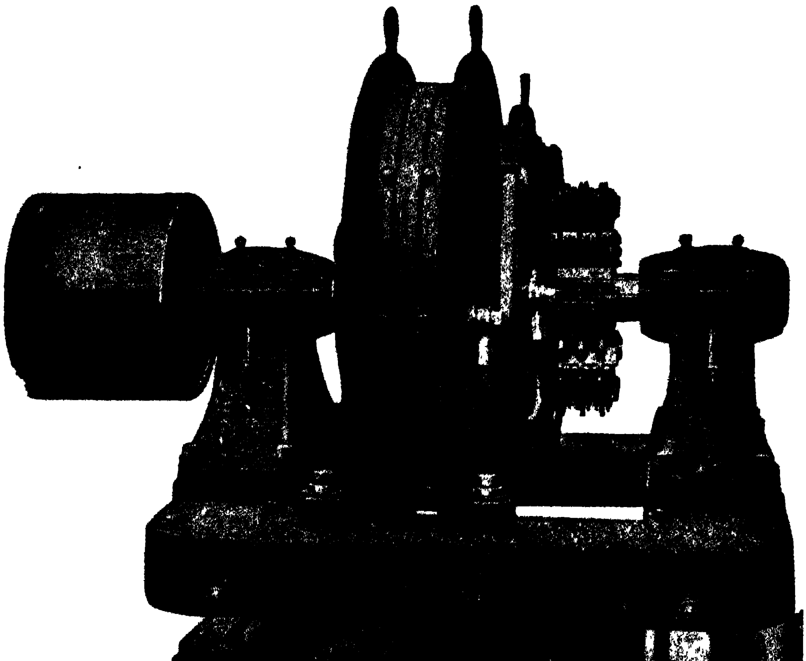


FIG. 372.—Ridgway 150 *k w*. 250 volt belted dynamo.

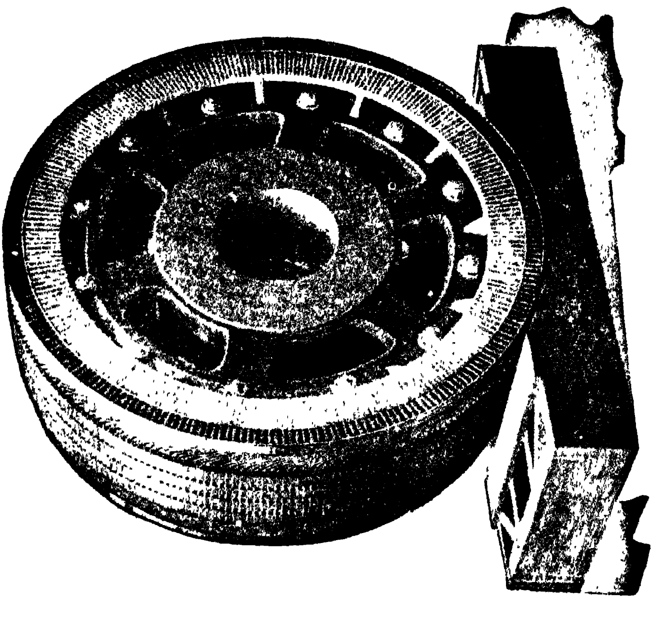


FIG. 373.—Ridgway 300 *k.w.* armature, back view.

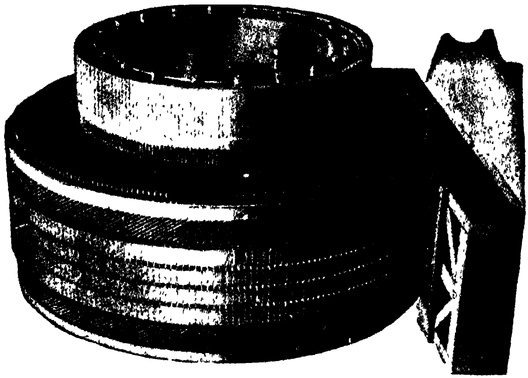


FIG. 374.—Ridgway 300 *k.w.* armature, front view.

The word dynamo is used to designate a machine which produces *direct current* as distinguished from *alternator* or machine generating an *alternating current*.

In a broader sense, the word *generator* is used to denote any machine generating electric current by electro-magnetic induction; the term therefore includes both dynamos and alternators.

The author objects to the word "generator," as the machine does not *generate* or *create electricity* but simply produces a pressure which causes the electricity (which already existed) to flow.

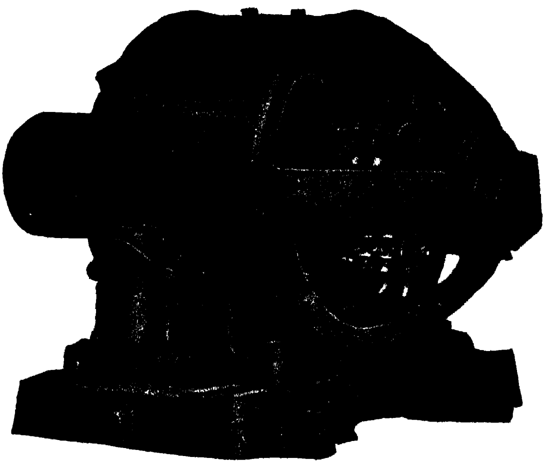
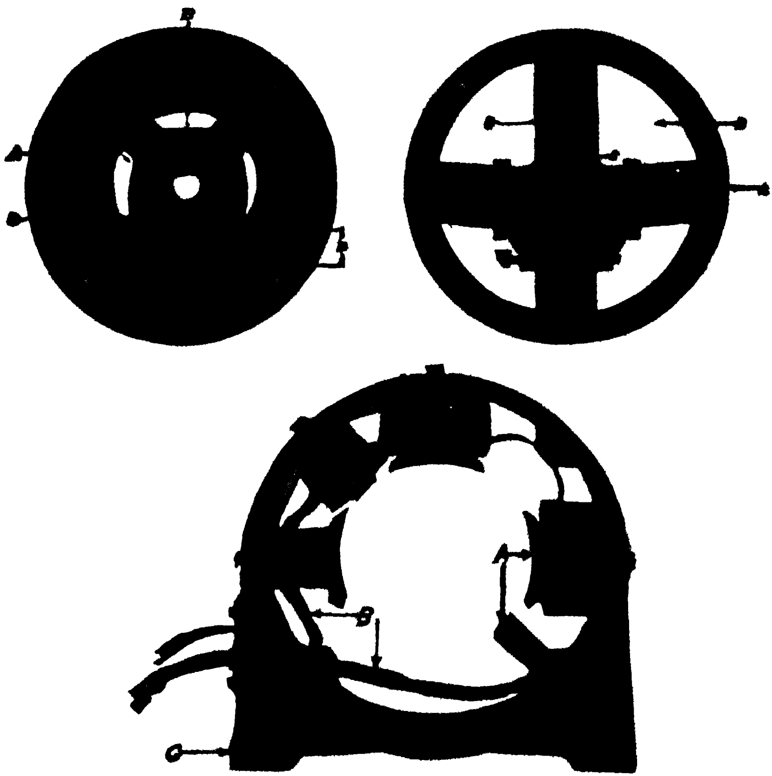


Fig. 375.—General Electric RC, dynamo with solid pulley end shield frame. Designed for lighting and power purposes in office buildings, factories, mills, hotels, residences, and other locations where the feeder length falls within reasonable limits, where Central Station current is not available, or partial *d c.* service is required as, for example, in manufacturing plants, machine shops, laundries, etc., in which a proportion of the machines used demand a variation in working speeds not readily or economically obtainable with *a.c.* motors.

Operation of a Dynamo.—A dynamo does not create electricity, but generates or produces an *induced* pressure which causes a current of electricity to flow through a circuit of conductors in much the same way as a force pump causes a current

of water to flow in pipes. The pressure generated in the dynamo causes the current of electricity to pass from a lower to a higher pressure in the machine, and from the higher, back to the lower pressure in the external circuit; that is, the dynamo generates electrical pressure which overcomes the *resistance* or opposition to the current flow in the circuit. The pump produces



FIGS. 376 to 378.—General Electric RC, dynamo construction. Fig. 376, solid pulley end shield frame; fig. 377, split pulley end shield; fig. 378, field assembly: A, laminated poles; B, wiring connections and terminals; C, cast feet.

a mechanical pressure which, for instance, may be used to force water into an elevated reservoir against the back pressure due to its weight.

The point to be emphasized is that *the dynamo does not create electricity* (nor the pump water) *but sets into*

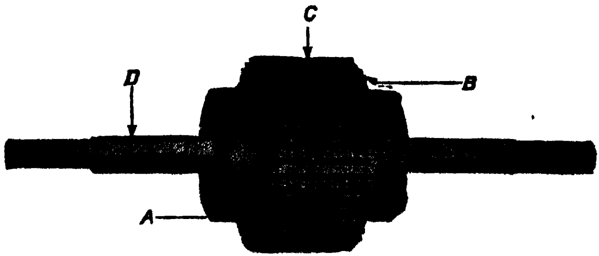


FIG. 379.—General Electric RC, dynamo armature construction. *The parts are:* A, punched laminations; B, outside punchings of extra thickness prevent vibration and flaring of inner discs; C, recessing for binding wire; D, heavy steel shaft ground to gauge.

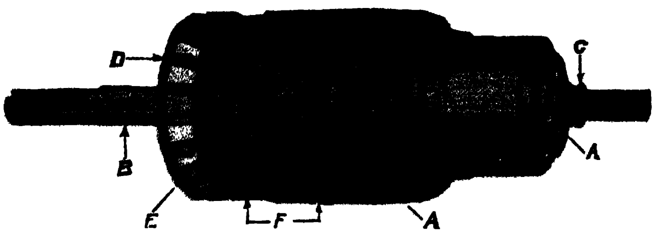
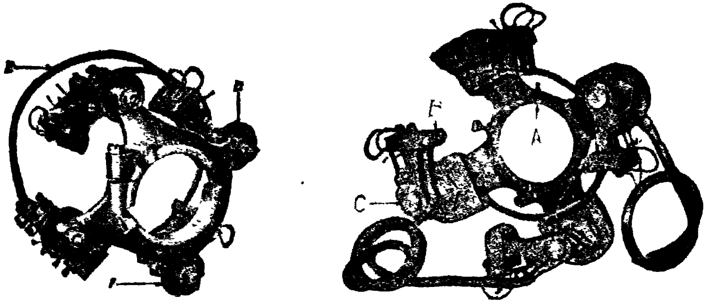


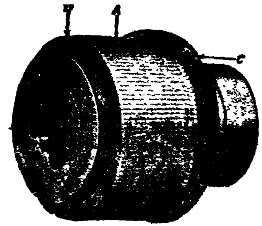
FIG. 380.—General Electric RC, dynamo armature complete. A, ventilating air ducts; B, shaft (removable); C, thrust collar; D, ventilating fan; E, coils held in toothed slots; F, binding wires.

motion something already existing by generating sufficient pressure to overcome the opposition to its movement.

Essential Parts of a Dynamo.—The dynamo in its simplest form consists of two principal parts:

NOTE.—The author objects to the standard terms *direct current generator* and *alternating current generator* in place of *dynamo* and *alternator*. Why use three words when one will do?





FIGS. 381 and 382.—General Electric RC, dynamo brush gear. A, heavy cast yoke; B, no dynamo with less than two brushes per stud; C, non-corrosive studs—will not turn in yoke; D, moulded bushings—non-shrinkable, non-hygroscopic; E, heavy cross-over connectors, F, long creepage space.

FIG. 383.—General Electric RC, dynamo commutator. A, liberal brush surface; B, ventilating ducts; C, slots for direct soldering of armature conductors, D, slotted mica.

1. The field magnets;
2. The armature.

Ques. What is the object of the field magnets?

Ans. To provide a field of magnetic lines or lines of force to be *cut* by the armature inductors as they revolve in the field.

Ques. What is an armature?

Ans. A collection of *inductors* mounted on a shaft and arranged to rotate in a magnetic field with provision for collecting the currents induced in the inductors.

A simple loop or turn or wire connected to a commutator may be considered as the simplest form of armature.

Ques. How do armatures and field magnets differ in dynamos and alternators?

Ans. A characteristic feature is that in the dynamo the field magnets are the stationary parts and the armature the rotating

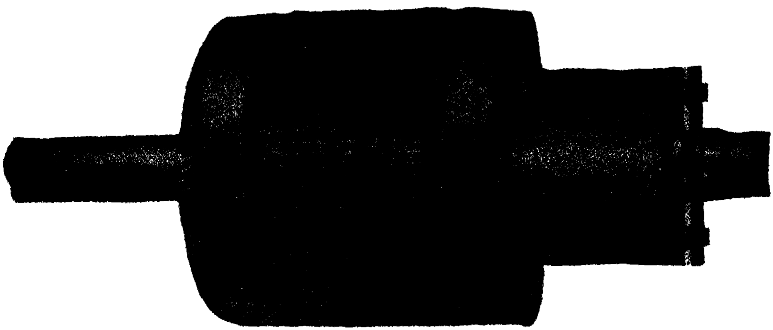


FIG. 384.- Armature of ideal three wire dynamo. The three wire system of direct current distribution has, in many places, certain advantages over the two wire.

part, while in the alternator the reverse conditions usually obtain.

Ques. With respect to this feature, what names are sometimes given to the armature and field magnets?

Ans. The *stator* and the *rotor* depending on which moves.

Ref. Letter	Description
A	Magnet frame, complete, two halves with dowel pins
B	#Stud fastening halves of magnet frame together
C	#Nut for stud "B"
D	Cover for magnet frame
E	Screw fastening cover "D" to magnet frame
F	Eyebolt for magnet frame
G	Main field coil
H	Pole piece for main field coil
I	Commutating field coil
J	#Pole piece for commutating field coil
K	Bolt fastening "H" and "J" to magnet frame
L	#Shim for "H" and magnet frame
M	#Shim for "J" and magnet frame
N	Brush-holder yoke
O	Set screw fastening brush-holder yoke to magnet frame
P	Brush-holder bracket with brush-holder stud
Q	Bolt fastening "P" to brush-holder yoke
R	Nut for "Q"
S	Washer for "R"
T	Insulation washer for "R"
U	#Insulation bushing for bolt "Q" and brush-holder bracket
V	Brush-holder, complete, including brush-holder body and shank, pressure arm and spring, rivets and screws
W	Hub and lever with pressure arm for "V"
X	#Screw fastening "W" to "V"
Y	Spring for brush-holder
Z	Screw fastening "V" to "P"
AA	Spring cotter for "W"
AB	Brush with pigtail and terminal
AC	Screw fastening brush pigtail terminal to brush-holder
AD	Inside bus ring with ears, terminal lug, rivets and insulation
AE	Outside bus ring with ears, terminal lug, rivets and insulation
AF	Terminal for cables on bus ring
AG	Bolt fastening "AF" to "AD" or "AE"
AH	Nut for bolt "AG"
AI	Lock washer for "AH"
AJ	#Cable clamp, two halves, complete
AK	#Support for "AJ"
AL	#Screw fastening "AK" to magnet frame
AM	#Insulator for cable and cable clamp
AN	Rotor, complete, with windings and commutator
AO	Set of rotor bars with slot insulation, wedges, binding wire, with insulation cord and tape
AP	Commutator, complete
AQ	#Key fastening commutator to armature flange
AR	Set of copper and mica segments with leads, finished and bound for commutator
AS	Shell for commutator
AT	Clamping ring for shell
AU	Bolt fastening clamping ring to shell
AV	Washer for bolt "AU"
AW	#Inner or outer mica cone for commutator
AX	#Mica collar between segments and commutator shell

FIG. 385.—General Electric MPO, dynamo showing parts and their names.

NOTE.—*Handling.*—Traveling cranes are exceedingly convenient in handling large machines. For stations not so equipped it is desirable to build a crib, or a horse of heavy timbers, for assembling the machines. This crib should be furnished by the purchaser, for it will be convenient and advantageous to retain it in the station for further use. The only safe method of supporting the armature while either moving or stationary is by slings or blocking under the shaft, or by a padded cradle under the core lamination. The shafts on 500 *k.w.* sets and larger are provided with an extension at either end beyond the portions which run in the bearings; these extensions are intended to facilitate the handling of armatures. Do not allow the weight of the armature and field frame to rest on the base before the base has been leveled and grouted and the grout has set hard. Avoid damaging any of the windings or other parts. The whole armature surface may be considered as subject to damage either to the bands, wedges, clips or insulation, unless properly handled. Commutator segments are very easily displaced, therefore an armature should never be lifted by passing a sling around the commutator. Always use a spreader when handling an armature to prevent the slings drawing over armature end clips, collector rings, or commutator. Slings placed on the magnet frame must be so drawn as to avoid chafing the field coil insulation.

Ques. What is the real distinction between an armature and a field magnet?

Ans. The name field magnet is properly given to that part which, whether stationary or revolving, ***maintains its magnetism***

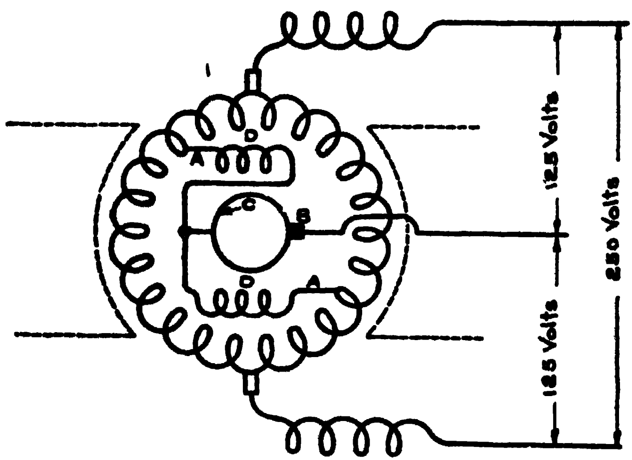


FIG. 386.—Scheme of winding connections of Ridgway three wire dynamo with balance coil. The diagram shows a two pole machine. From electrically opposite points A,A, on the armature winding, connections are made to the terminals of balance coil DD. At the center of the balance coil a connection is made to a slip ring C, and the neutral is taken directly from this ring through the brush B. The balance coil is wound on a laminated core bolted to the back of the armature spider and protected by a heavy cast iron shield. The slip ring is bolted to the commutator shell and the holder for the carbon brush is mounted on the adjacent outboard bearing. The details of construction of the three wire dynamo are exactly the same as the two wire dynamo, except for the addition of the balance coil and connections as just described, and a slight change in the compensating coil connections, whereby they are divided into two parts, one of which is connected into the positive and the other into the negative lead.

steady during operation; the name armature is properly given to that part which, whether revolving or fixed, ***has its magnetism changed in a regularly repeated fashion when the machine is in motion.***

Construction of Dynamos.—In the make up of a dynamo, as actually constructed, there are five principal parts, as follows:

1. Bed plate;
2. Field magnets;
3. Armature;
4. Commutator;
5. Brushes.

TEST QUESTIONS

1. *What is a dynamo?*
2. *What is the objection to the use of the word "generator"?*
3. *Does a dynamo create electricity?*
4. *Describe in detail the operation of a dynamo.*
5. *What points should be emphasized in explaining the action of a dynamo?*
6. *What are the essential parts of a dynamo?*
7. *What is the object of the field magnet and armature?*
8. *What is the real distinction between an armature and a field magnet?*
9. *Name five principal parts in the construction of a dynamo.*

CHAPTER 13

The Dynamo; Basic Principles

A dynamo is *a machine for converting mechanical energy into electrical energy, by means of electro-magnetic induction, the amount of electric energy thus obtained depending upon the mechanical energy originally supplied.*

The word dynamo is properly applied to a machine which "generates"* direct current, as distinguished from the alternator, which "generates" alternating current.

Ques. Define a dynamo with respect to its principle of operation.

Ans. A dynamo is *a machine for filling and emptying conducting loops with magnetic flux, and utilizing the electric pressure thus induced in them for the production of current in the external circuit.*

The fitness of this definition is apparent, having in mind the principles of electro-magnetic induction.

Ques. What are the three essential parts of a dynamo?

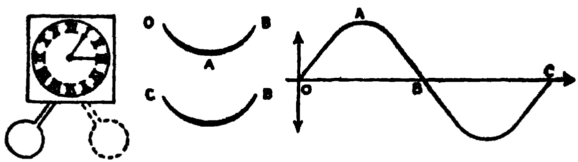
Ans. The field magnet, armature, and commutator.

*NOTE.—*It should be understood that a dynamo does not generate electricity*, for if it were only the quantity of electricity that is desired, it would be of no use, as the earth may be regarded as a vast reservoir of electricity. However, electricity without pressure is incapable of doing work, hence a dynamo, or so called "generator," is necessary *to create an electric pressure by electro-magnetic induction in order to cause the electricity to flow against the resistance of the circuit and do useful work.* The author objects to the term *generator*, although it is now commonly but erroneously used. A so-called "generator" does not generate electricity.

Ques. What is the object of the field magnet?

Ans. To provide a magnetic field, through which the conducting loops arranged on a central hub and forming the ***armature*** are carried, or the flux carried through them, so that they are successively filled and emptied of magnetic lines.

Ques. What is a commutator?



FIGS. 387 to 390.—Alternating current. ***The variations*** of such a current may be represented by the speed variations in the pendulum of a clock. The pendulum swings first in one direction and then in the other. At the end of each swing it slows down to a complete stop and then gradually speeds up in the opposite direction. As it passes through the lowest point it travels at a maximum speed. Traveling toward the center its speed increases continually, and traveling away from the center its speed decreases continually. If a curve be made by plotting the speed with time, and plotting the curve for a right swing above a reference line and the curve for a left swing below it, a diagram such as shown will be produced. The point O, indicates zero speed when the pendulum is at the extreme left and is just about to start on the right swing. The point A, represents the speed of the pendulum as it passes through the center. The point B, represents the end of the right swing with the pendulum stopped and ready to start the left swing and so on. Immediate points represent the speed at corresponding times throughout the swing. Electricians use the same form of curve plotted with time to show the variations of current, current being substituted for speed.

Ans. A device for causing the alternating current generated in the armature to flow in the same direction in the external circuit.

Ques. Upon what does the voltage depend?

Ans. Upon the *rate* at which each conducting loop is filled and emptied of lines of force and the number of such loops with their grouping or connection.

Ques. How is the operation of a dynamo best explained?

Ans. By considering first the action of the simplest form of current generator, or elementary alternator.

Ques. Describe an elementary alternator.

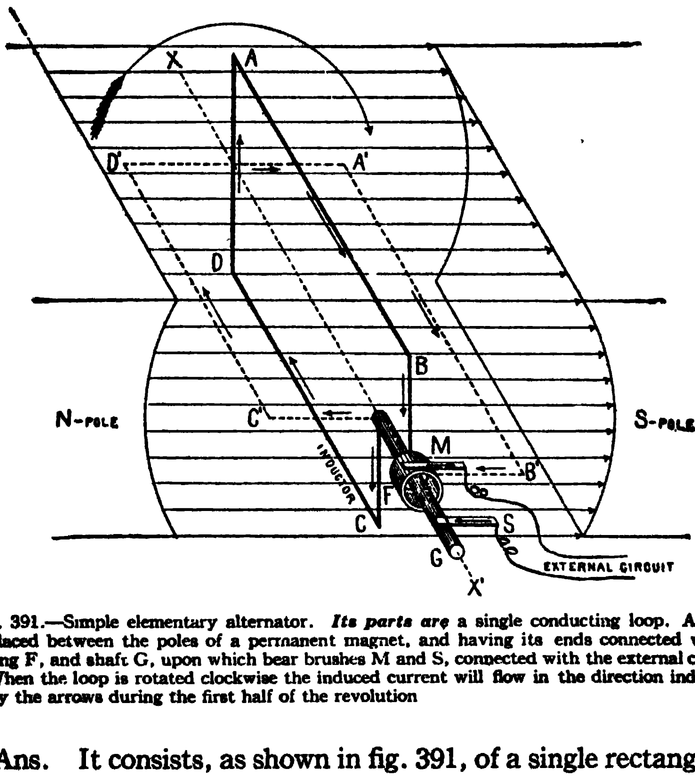


FIG. 391.—Simple elementary alternator. *Its parts are* a single conducting loop. ABCD, placed between the poles of a permanent magnet, and having its ends connected with a ring F, and shaft G, upon which bear brushes M and S, connected with the external circuit. When the loop is rotated clockwise the induced current will flow in the direction indicated by the arrows during the first half of the revolution

Ans. It consists, as shown in fig. 391, of a single rectangular loop of wire ABCD, one end being attached to a ring F, and the other to the shaft G, and arranged so as to revolve around the axis XX′, which is located midway between the two poles

of the magnet. Two metallic strips or *brushes* M and S, connected with the external circuit, bear on the ring F and shaft G, respectively, in order to "collect" the current generated in the armature when the machine is in operation. The long, straight, horizontal arrows joining the two poles of the magnet, represent the *lines of force* which make up the magnetic field between the poles. The field is here assumed to be uniform, as indicated by the equal spacing of the arrows.

Ques. What happens when the loop is rotated?

Ans. According to the law of electro-magnetic induction, when the loop is rotated around its horizontal axis in the direction indicated by the curved arrow, an electric pressure will be induced in the loop, the magnitude of which depends on the *rate* of change of the number of lines of force threading through, or embraced by the loop.

That is, if the number of lines embraced by the loop be increased from, say, 0 to 1,000, or decreased from 1,000 to 0, in one second, the electric pressure generated will be two times as great as if the increase or decrease were only 500 lines per second.

Ques. Upon what does the direction of the induced current depend?

Ans. Upon the direction of the lines of force and direction of rotation of the loop.

Ques. How is Fleming's rule applied to determine the direction of current?

Ans. In applying this rule, the horizontal portion of the loop, such as AB or CD (fig. 391), is to be considered as moving up or down; that is, the component of its motion at right angles to the lines of force is taken as the direction of motion. When the loop is in the position ABCD, such that its plane is vertical

or perpendicular to the lines of force, the maximum number of magnetic lines thread through it, but when it is in a horizontal position A′B′C′D′, so that its plane is parallel to the lines of force, no lines pass through the loop. During the rotation from position ABCD to A′B′C′D′, the number of lines passing through the loop is *reduced* from the maximum to zero,

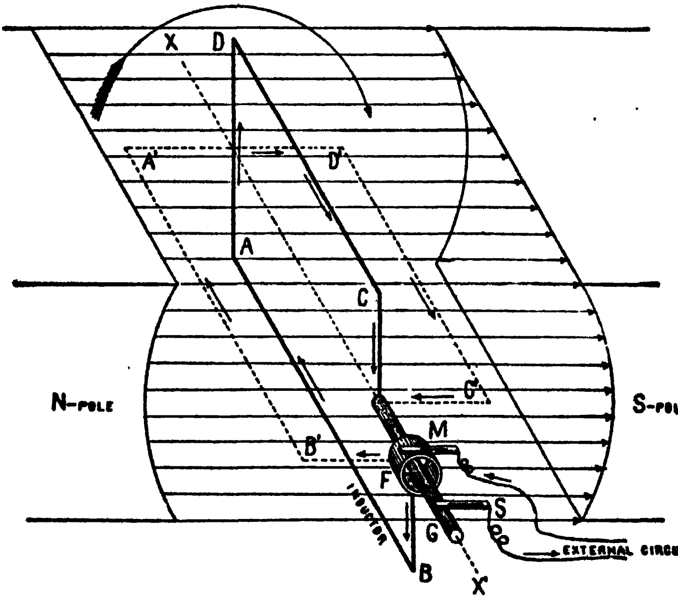


FIG. 392.—Simple elementary alternator, showing reversal of current when the loop has [illegible] one half revolution from the position of fig. 391. It should be noted that AB, for instance, which has been moving *downward* during the first half of the revolution (fig. 391), moves *upward* during the second half (fig. 392); hence, the current during the latter interval flows in the opposite direction.

the reduction taking place with *increasing rapidity* as the loop approaches the horizontal position, the electric pressure thus induced *increasing in like proportion*. Continuing the rotation from the horizontal position A′B′C′D′, to the inverted

vertical position ABCD (fig. 392), the number of lines passing through the loop is increased from zero to the maximum, the increase taking place *with decreasing rapidity* as the loop approaches the inverted vertical position, the elecric pressure thus induced *decreasing in like proportion.*

Ques. How does the current flow during the first half of the revolution of the loop?

Ans. It flows in the direction ABCD (fig. 391), as is easily ascertained by aid of Fleming's rule.

Ques. What is the path of the current to the external circuit?

Ans. It flows out through brush M (fig. 391), and returns through brush S, thus making M, positive and S negative.

Ques. What occurs during the second half of the revolution?

Ans. The wire AB (fig. 392), which before was moving in a downward direction, moves in an upward direction; hence, the current is reversed and flows around the loop in the direction ADCB (fig. 392), going out through brush S, and returning through brush M. This makes M, negative and S, positive.

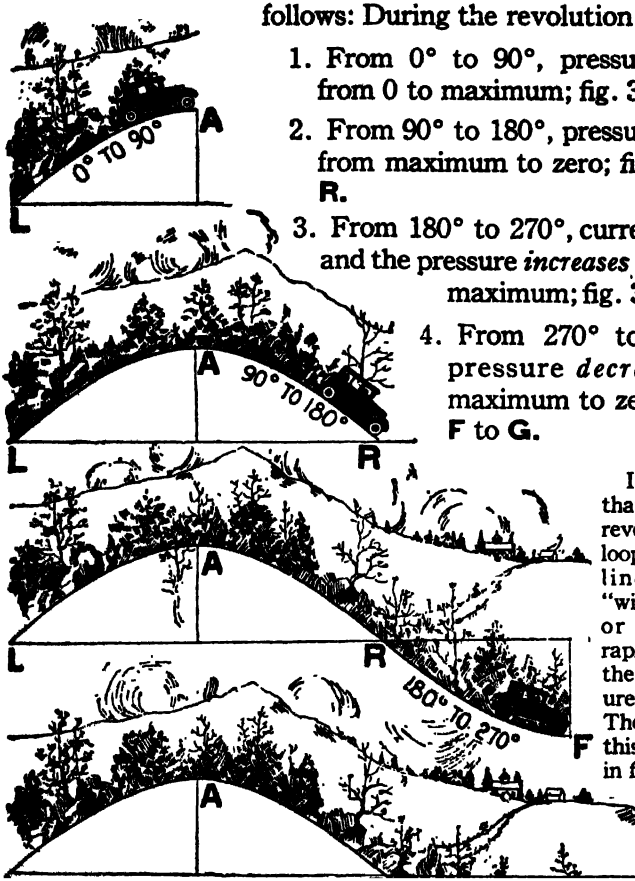
Ques. What may be said of the pressure during the second half of the revolution?

Ans. It varies in a similar manner as in the first half of the revolution: that is, the magnetic lines are cut *with increasing rapidity* during the third quarter, and *with decreasing rapidity* during the fourth quarter of the revolution, which causes the electric pressure to increase and decrease during these intervals.

The cycle of events just described may be summed up as follows: During the revolution of the loop:

1. From 0° to 90°, pressure *increases* from 0 to maximum; fig. 393, **L** to **A.**
2. From 90° to 180°, pressure *decreases* from maximum to zero; fig. 394, **A** to **R.**
3. From 180° to 270°, current *reverses* and the pressure *increases* from zero to maximum; fig. 396, **R** to **F.**
4. From 270° to 360°, the pressure *decreases* from maximum to zero; fig. 396 **F** to **G.**

It was stated that, during the revolution of the loop, the magnetic lines were cut "with increasing or decreasing rapidity," causing the electric pressure to rise or fall. The reason for this is illustrated in fig. 397.



Figs. 393 to 396.—Automobile on hilly road illustrating the *sine curve* as applied to *a.c.* cycle. Fig. 393, car rises from level, ground L, to maximum elevation; fig. 394, descends from A, back to initial level R, fig. 395, descends from initial level R, to lowest point F; fig. 396, rises from lowest point F, to initial level G. The pressure, or current reverses at the point R.

The loop is here shown in a horizontal position at right angles to the direction of the magnetic field; the latter, as indicated by the even spacing of the vertical arrows representing the magnetic lines, is assumed to be uniform.

The wire CD, of the loop, as it rotates at *constant speed*, cuts the magnetic lines at the points 0, 1, 2, 3, etc., but the distances 01, 12, 23, etc.,

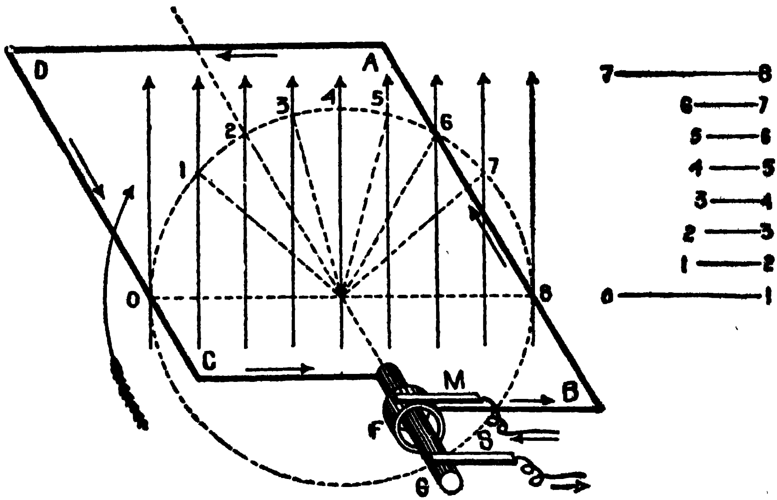


FIG. 397.—Illustrating the increase and decrease in the rate magnetic lines are cut by a revolving loop. The initial position of the loop is taken at right angles to the direction of the lines of force. Since the loop rotates at a constant speed, it is evident that it does not cut the magnetic lines at uniform rate, because the intercepted arcs 01, 12, etc., are unequal. These arcs rectified at the right by the horizontal lines 01, 12, etc., show more clearly the increase and decrease in the rate at which the magnetic lines are cut.

between these points, are unequal; that is, the wire CD, travels farther in cutting the lines 0 and 1, than it does in cutting 1 and 2, and still less in cutting the lines 2 and 3. After cutting the line 4, which passes through the axis of revolution, the opposite conditions obtain.

If the arcs 01, 12, etc., of the dotted circle, which are intercepted by the magnetic lines and passed through by the wire, be rectified and laid down under each other, as lines 01, 12, etc., the time of passage of the wire between successive magnetic lines will vary as the length, since the speed is uniform. Thus the wire in passing from line 0 to line 1, takes

much more time than in passing from 1 to 2, as indicated at the left of the figure by 01 and 12, and still less in passing from 2 to 3; that is, the rate of cutting the lines increases as CD, rotates from 0 to 4 and decreases from 4 to 8.

Since similar conditions prevail with respect to AB, for its corresponding movement, it is evident that the number of lines which thread through the loop are *decreased with increasing rapidity* as the loop rotates through the first quarter of a revolution, and *increased with decreasing rapidity* during the second quarter of the revolution. Moreover, it must be evident that the reverse conditions obtain for the third and fourth quarters of the revolution.

The Sine Curve.—In the preceding paragraph it was shown that an alternating current is induced in the armature of either an alternator or dynamo; that is, the current:

1. Begins with zero pressure;
2. Rises to a maximum;
3. Decreases again to zero;
4. Increases to a maximum in the opposite direction, and
5. Decreases to zero.

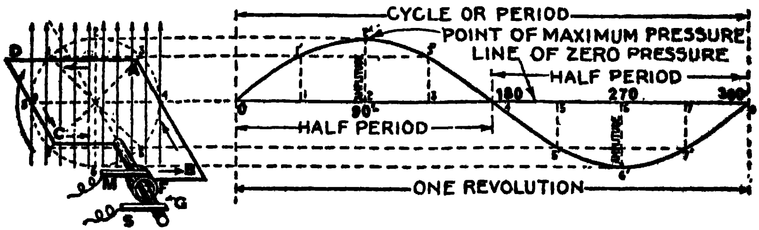
A wave like curve, as shown in fig. 399, is used to represent these several changes, in which the horizontal distances represent time, and the vertical distances, the varying values of the electric pressure

It is called the sine curve because a perpendicular at any point to its axis is proportional to the sine of the angle corresponding to that point.

Ques. Describe the construction and application of the sine curve.

Ans. In fig. 398, at the left, is shown an elementary armature in the horizontal position. but at right angles to the magnetic field. The dotted circle indicates the circular path described by AB, or CD, during the revolution of the loop. Now

as the loop rotates, the induced pressure will vary in such a manner that *its intensity at any point of the rotation is proportional to the sine of the angle corresponding to that point.* Hence, on the horizontal line which passes through the center of the dotted circle, take any length, as 08, and divide it into any number of parts representing fractions of a revolution, as 0°, 90°, 180°, etc. Erect perpendiculars at these points, and



FIGS. 398 and 399.—Application and construction of the sine curve. The sine curve is a wave-like curve used to represent the changes in strength and direction of an alternating current. An elementary alternator is shown at the left to illustrate the application of the sine curve to the alternating current cycle. *It consists of* a loop of wire ABCD, whose ends are attached to the ring F and shaft G, being arranged to revolve in a uniform magnetic field indicated by the vertical arrows which represent magnetic lines at equi-distances. The alternating current induced in the loop is carried to the external circuit through the brushes M and S. Now, as the loop rotates, the induced electromotive force will vary in such a manner that its *intensity at any point of the rotation is proportional to the sine of the angle corresponding to that point*, this is represented by the wave-like curve. The mean value of the sine curve, or *average electromotive force* developed during the revolution, or *period*, is equal to 2 ÷ π, or .637 of that of the maximum ordinate, that is, average electromotive force = .637 × *amplitude*. The sine curve lies above the horizontal axis during the first half of the revolution and below it during the second half, which indicates that the current flows in one direction for a half revolution and in the opposite direction during the remainder of the revolution.

from the corresponding points on the dotted circle project lines parallel to 08. The intersections with the perpendiculars give points on the sine curve. Thus the loop passes through 2, at the 90° point of its revolution, hence, projecting over to the corresponding perpendicular gives 22′, a point whose elevation from the axis is proportional to the electric pressure at

that point. In like manner other points are obtained, and the curved line through them will represent the variation in the electric pressure for all points of the revolution.

At 90°, the pressure is at a maximum; hence, by using a pressure scale such that the length of the perpendicular 22′ for 90° will measure the maximum voltage the length of the perpendicular at any other point will represent the actual pressure at that point.

The curve lies above the horizontal axis during the first half of the revolution, and below it during the second half, which indicates that

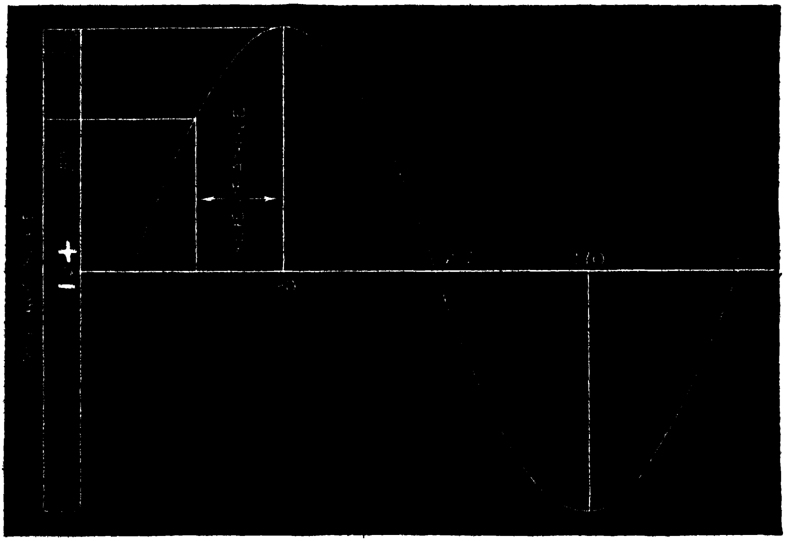
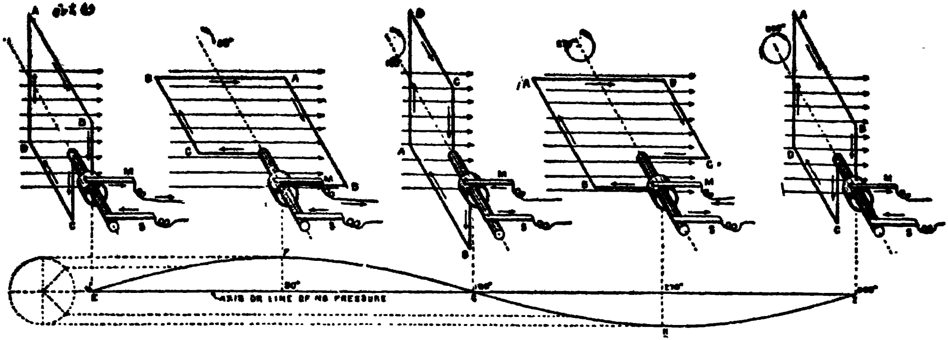


FIG. 400.—Sine curve and voltage scale illustrating variation and reversal of pressure during the alternating cycle as measured by the sine of the angle.

the current flows in one direction for a half revolution and in the opposite direction during the remainder of the revolution.

The application of the sine curve to represent the alternating cycle, is further illustrated in figs. 401 to 407, which show the position of the armature at each quarter of the revolution.

In fig. 401, the loop ABCD, is in the vertical position at the



FIGS. 401 to 407.—The sine curve, with view of armature for each 90° of the revolution, showing progressively the application of the sine curve to the alternating current cycle.

beginning of the revolution. At this instant the pressure is zero, hence the sine curve as shown begins at E, the zero point, that is, on the axis or line of no pressure.

As soon as the loop rotates out of the vertical plane, the pressure rises and the current begins to flow in the direction indicated by the arrows, going out to the external circuit through brush M, and returning through brush S.

Continuing the rotation, the pressure increases in proportion to the sine of the angle made by the plane of the loop with the horizontal, until the loop comes into the horizontal position illustrated in fig. 402. This increase is indicated by the gradual rise of the sine curve from E to F. The loop has now made one quarter of a revolution and the pressure reached its maximum value.

As the loop rotates past the horizontal position of fig. 402, the electric pressure gradually decreases in intensity, reaching the zero point at the end of the second quarter, that is, when the loop has turned one half revolution. This is indicated by the gradual fall of the curve from F, to G.

When the loop turns out of the vertical position shown in fig. 403, the current reverses, because the movement of AB,

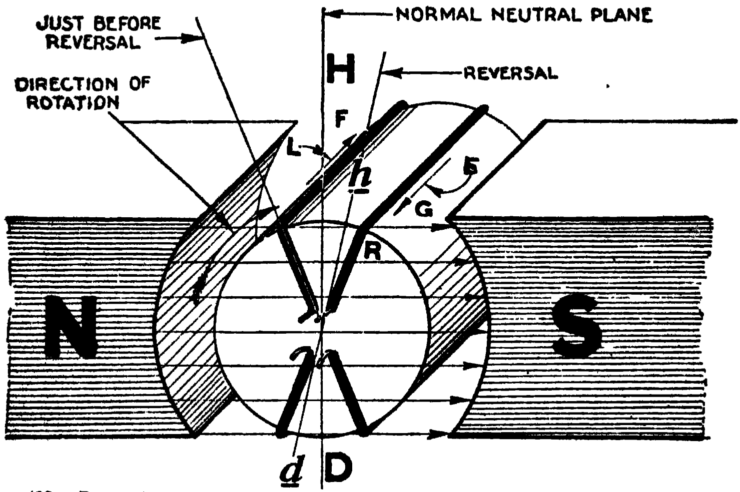


FIG. 406.—Reversal of armature current. ***For illustration***, assuming no field distortion or self induction in the coil, the current will flow in the direction L, until the coil shown reaches the normal neutral plane HD. Here the current or pressure is zero, and for position beyond HD, as R, the current flows in the reverse direction F. In the actual machine, the current does not reverse at HD, but at some later position as *hd*, owing to field distortion and self-induction.

and CD, is reversed; at this instant the brush M, becomes negative, and S, positive. This reversal of current is indicated by the curve falling *below* the axis from G, to I.

During the second half of the revolution, figs. 403 to 405, the changes that occur are the same as in the first half, with the exception that the current is in the reverse direction; these changes are as shown by the curve from G, to I.

TEST QUESTIONS

1. *Define a dynamo with respect to its principle of operation.*
2. *What are the three essential parts of a dynamo?*
3. *What is the object of the field magnet?*
4. *What is a commutator?*
5. *Describe in detail the operation of an elementary alternator.*
6. *How is the Fleming's rule applied to determine the direction of current?*
7. *What is the sine curve?*
8. *Describe the construction and application of the sine curve.*

CHAPTER 14

The Dynamo; Current Commutation

How the Dynamo Produces Direct Current: The Commutator.—The essential difference between an alternator and a dynamo is that *the alternator delivers alternating current to the external circuit while the dynamo delivers direct current.*

In both machines, as before stated, alternating current is induced in the armature, but the kind of current delivered to the external circuit depends on the manner in which the armature current is collected.

In the case of an alternator, the method is quite simple. As previously explained, each end of the loop is connected with an insulated collector ring carried by the shaft, the current being collected by means of brushes which bear against the rings. This principle, rather than the actual construction, is shown in the preceding illustrations. Its important point, as distinguished from other methods of collecting the current, is that *each end of the loop is always in connection with the same brush.*

Ques. How is direct current obtained in a dynamo?

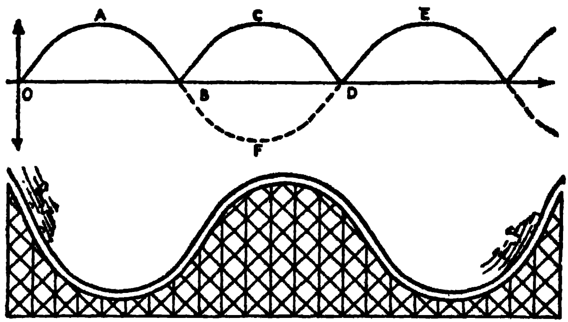
Ans. A form of rotating switch called the *commutator* is placed between the armature and the external circuit and so arranged that it will reverse the connections with the external circuit at the instant of each reversal of current in the armature.

Ques. How is a commutator constructed?

Ans. It consists of a series of copper bars or segments arranged side by side forming a cylinder, and insulated from each other by sheets of mica or other insulating material.

Ques. Where is the commutator placed?

Ans. It is attached to the shaft at the front end of the armature.



FIGS. 409 and 410.—Rectified current. The alternating current generated in the armature of a dynamo is rectified by reversing every other half wave. Variations in speed which correspond with variations in rectified current might be produced by a car on a scenic railway, as shown. The car gradually increases in speed as it moves down a dip, attaining maximum speed at the bottom, then gradually losing speed until it comes to a practical stop at the top of the following rise, after which the same cycle is repeated. If the speed of the car be plotted with time, at the start of the rise, the speed is zero as represented by the points O,B,D, etc. At the top of the curve where the speed is minimum, the corresponding point on the curve is A,C,E, etc. Any points in between these represent the speed at corresponding points on the inclines of the railway. It will be seen that the shape of these waves is exactly the same as those drawn for the pendulum, except that they are all on the same side of the reference line; that is, there is no reversal of direction, the car is always running in the same direction but at continually varying speed. If the car should swing back upon reaching the start of the second rise which corresponds to B, instead of continuing on the same side, the speed curve would be represented by the dotted curve B F D, and would represent an alternating current. By continuing on instead of backing up, the curve B C D, is obtained. This is exactly what happens with the rectified current. When the current has increased to a maximum and then decreases to zero, instead of reversing, it increases to a maximum again in the same direction. The curve representing a rectified current has the same shape as the alternating current which is rectified, except that it is all in the same direction. Therefore, it is continually fluctuating from zero to a maximum value—a condition very unfavorable from the standpoint of steady light.

Ques. What are inductors?

Ans. The insulated wires wound on the armature core, and in which the electric current is induced.

Ques. How are the inductors connected to the commutator?

Ans. The ends of each conducting loop or coil must be connected with the commutator segments in a certain order to correspond with the type of winding.

Ques. Explain in detail how direct current is obtained in a dynamo.

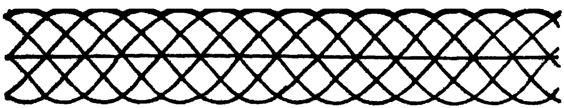
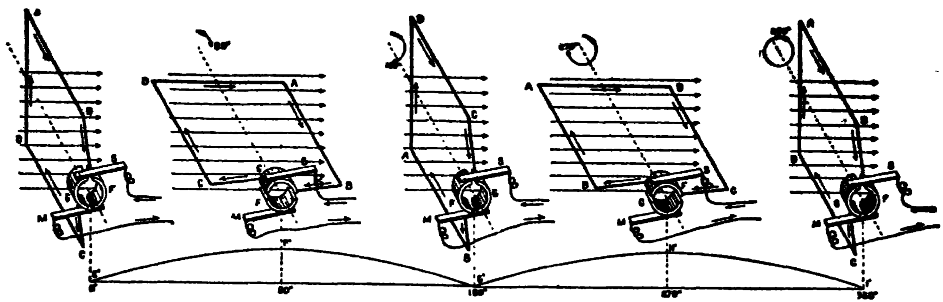


FIG. 411.—Production of direct current. A dynamo consists in reality of a number of elemental alternators, each one connected to a pair of segments which are assembled with a large number of similar ones to form a ring known as a commutator. This commutator is connected to the outside circuit through a pair of brushes and as it revolves the brushes connect first one of these elemental generators and then the next to the outside circuit. If each one of the generating systems connected to a pair of segments be represented, as producing an alternating current wave as shown in fig. 393, then a number of these elements would produce a corresponding number of waves as here shown. When the machine revolves, the circuit is then connected to one wave after another, the shift being made when the brush passes from one segment to the next. The points of shifting are where the waves intersect each other. Therefore, the current in the outside circuit would be produced by the tops of the individual waves and represented by the heavy line shown in the curve system.

Ans. It will be easily seen by the aid of a series of illustrations just how the alternating armature currents are transformed into direct current. When the loop is in the vertical position, as shown in fig. 412, brush M, is in contact with segment F, and S with G. As the armature rotates, the current flows for one half revolution in the direction AB, through



FIGS. 412 to 417.—Commutation of the current. These figures show how a dynamo transforms alternating into the so called direct current. During the first half of the revolution the current flows in the direction AB, out through segment F, of the commutator and brush M, returning through brush S and segment G, figs. 412 and 413. At the beginning of the second half of the revolution, fig. 414, the current in the armature reverses and flows around the loop in the direction BA. At this instant the brushes M and S, pass the gaps between the commutator segments, thus reversing contact with the segments, and causing the current in the external circuit to remain in the same direction.

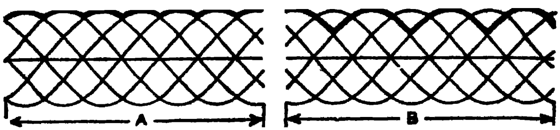
segment F, and out to the external circuit through brush M, as shown in figs. 412 and 413, returning through brush S, and segment G. At the beginning of the second half of the revolution, fig. 414, the current in the loop reverses and flows in the opposite direction BA, as indicated by the arrows. At this instant, however, the brushes M and S, pass out of contact with segments F and G, and come into contact with G and F, respectively; that is, M, leaves F, and contacts with G, while S, leaves G, and contacts with F. The effect of this is *to reverse the connections with the external circuit at the instant the alternation or reversal of current in the armature takes place,* thus keeping the current in the external circuit in the same direction.

Ques. How is this indicated by the sine curve?

Ans. The sine curve, instead of falling below the axis, as in figs. 401 to 407, again rises as in the first half of the period, that is G′H′I′, is identical with E′F′G′.

Ques. Is the direct current indicated by the sine curve in figs. 412 to 417 continuous?

Ans. *No;* it is properly described as a *pulsating current,* or one, constant in direction, but periodically varying in intensity so as to progress in a series of throbbings or pulsations instead of with uniform strength.



FIGS. 418 and 419.—Comparison of large and small commutators. Fig. 419 shows effect of reducing the number of segments one half. The difference in fluctuation in the current is shown by heavy lines which joins the tops of the curves. The A. section shown in fig. 418 represents the larger number of segments.

Ques. What is generally understood by the word "continuous" as applied to the current obtained from a dynamo?

Ans. It is usually accepted as meaning a steady or non-pulsating direct current; one that has a uniform pressure and constant direction of flow as opposed to an alternating current.

Ques. Is a continuous current ever obtained with a dynamo?

Ans. *No.*

It should be clearly understood at the outset that it is impossible to obtain a continuous current with a dynamo. The so called continuous current which it is said to produce is in reality a pulsating current, but with pulsations so minute and following each other with such rapidity that the current is practically continuous, and as such is generally called continuous.

Ques. How is the so called continuous current produced by a dynamo?

Ans. In order to obtain a large number of small pulsations per revolution of the armature instead of two large pulsations, as with the single loop armature, the latter must be replaced by one having a great number of loops properly connected to

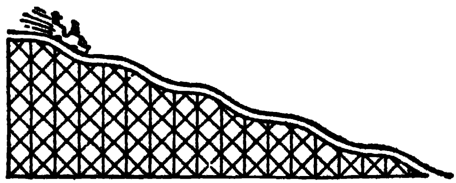


FIG. 420.—Direct current fluctuations. The current in the circuit fed from a dynamo fluctuates continually in value, but with a large number of commutator segments the magnitude of these fluctuations is entirely negligible. The disturbance that might be produced by such fluctuations may be compared to the changes in speed that would be produced in a car by waves in the track of an inclined railway; that is, a few large waves would produce greater disturbances than a large number of small waves. Likewise a large diameter commutator will produce a steadier current. and consequently a steadier light than a small commutator with a smaller number of segments.

commutator segments and so arranged that the successive loops begin the cycle progressively.

The difficulties encountered in connecting up numerous loops were overcome by Gramme, who, in 1871 invented a "ring" armature. His method consists in winding a ring with a continuous coil of wire, connections being made at suitable intervals with the commutator.

In order to understand the action of such an arrangement, it will be well to first consider four separate coils wound on a ring as shown in fig. 421. These coils are all similar, but at the moment occupy different magnetic positions on the ring. The rotation being clockwise, 1, is about

to enter the field adjacent to the north pole, while 2, is emerging from the field in the region of the south pole. Again, 3, is approaching the south pole and 4, receding from the north pole.

Ques. Describe in detail the action of the four coils wound around the ring as in fig. 421.

Ans. According to the laws of electro-magnetic induction, pressures are set up at the ends of the coils such as tend to produce currents in the directions indicated by the arrows. Now, assuming the pressures in coils 1 and 2, to be equal, if

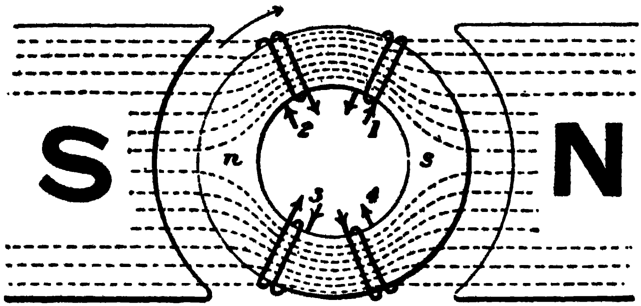
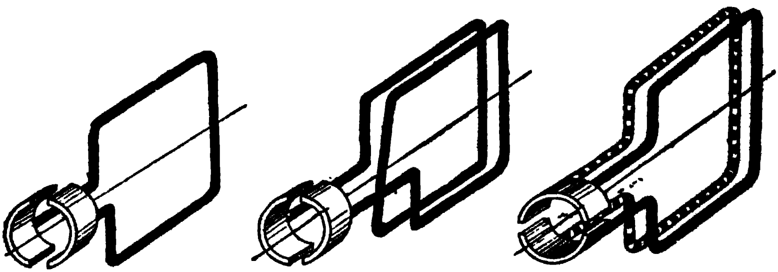


FIG. 421.—Four separate coils wound on ring to illustrate the action of a Gramme ring armature. If the ring be rotated the electric pressure induced in adjacent coils will be equal and tend to produce currents in opposite directions; hence, if the inner ends be joined, the junctions would be at a higher pressure (+ or −) than the loose ends. With proper connections current may be collected at the junctions.

the adjacent ends be joined, no flow of current will take place, but the junction will be at a higher pressure than the loose ends of the coils and if a wire be attached to this junction, and the necessary circuits completed, a current will flow along the wire outward from the junction. Similarly, if the adjacent ends of coils 3 and 4, be joined, there will be no flow of current, but the junction will be at a lower pressure than the loose ends, and if a wire be attached to the junction and the necessary circuits completed, current will flow from the junction around the coils.

Ques. What may be said with respect to the four coil Gramme ring armature shown in fig. 429?

Ans. According to the laws of electromagnetic induction, with the north pole of the field at the left and clockwise rotation, the induced currents flow *upward* on both sides of the ring, hence, *the pressures oppose each other at only two of the junctions,*



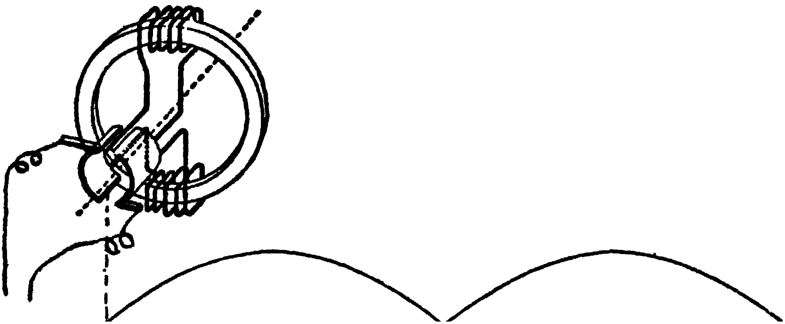
FIGS. 422 to 424.—Elementary dynamo armatures. Fig. 422, single turn loop; fig. 423, coil of two turns *in series;* fig. 424, coil of two turns *in parallel.* *In operation* the amplitude or maximum pressure induced with the two turn coil, fig. 423, is double that of a single turn loop, fig. 422. In fig. 423, the pressure is double that induced in fig. 424, while the amount of current generated with series turns, fig. 423, is only half that generated with turns in parallel fig. 424.

FIGS. 425 and 426.—Gramme ring armature with one coil, and characteristic sine curve below. With one coil as shown, there are two pulsations of the current per revolution of the armature.

namely; at the one connected to brush M, where the pressures on either side are both directed toward the junction and the other at the junction connected to brush S, at which the pressures are both directed from the junction.

It is evident, then, that the pressure at M, is higher than at S; that is, M, is positive and S, negative; consequently, the current flows from M to the external circuit and returns through S.

Ques. In what other way may the four coils of the armature in fig. 429 be regarded?



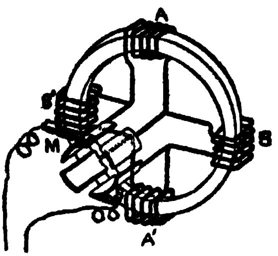
FIGS. 427 and 428.—Gramme ring armature with two coils placed 180° apart. *This arrangement* gives double the pressure of the one coil armature, fig. 425.

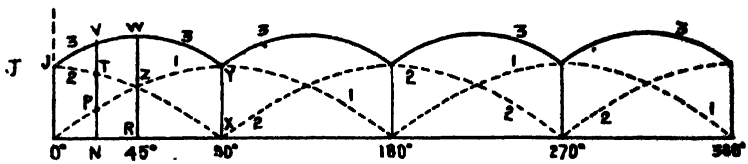
Ans. They may be considered as two pairs AA′ and BB′, the action of either pair being identical with the two coil armature shown in fig. 427; this, in turn, produces the same effect as the one coil armature of fig. 425, with the exception that the amplitude of the current generated with two coils is twice as great as that with one coil of the same number of turns.

Again considering the action of the four ring coil shown in fig. 429, and starting at the beginning of the revolution, the variation of pressure induced in coils AA′, is indicated by the dotted sine curve 1, and of BB′, by dotted curve 2. It will be seen that 1, begins at the axis or line of no pressure, and 2, at maximum pressure.

The two curves overlap each other, and in order to determine the effect of this it is necessary to trace the resultant curve 3. This is easily done, as the resultant pressure induced at any point in the revolution of the armature is equal to the sum of the pressures induced in AA′ and BB′. Thus, at the beginning of the revolution the pressure induced in AA,′ is at zero point, and in BB′ at its maximum J, hence, the resultant curve begins at the point J. Again, for any point in the revolution, as N, the height of the resultant curve is equal to $NP+NT=NV$. For 45° or ⅛ revolution, the resultant curve reaches its amplitude, which is equal to $2\times RZ=RW$, and at 90° it again reaches its minimum, XY.

Ques. State the conditions upon which the steadiness of the current depends.



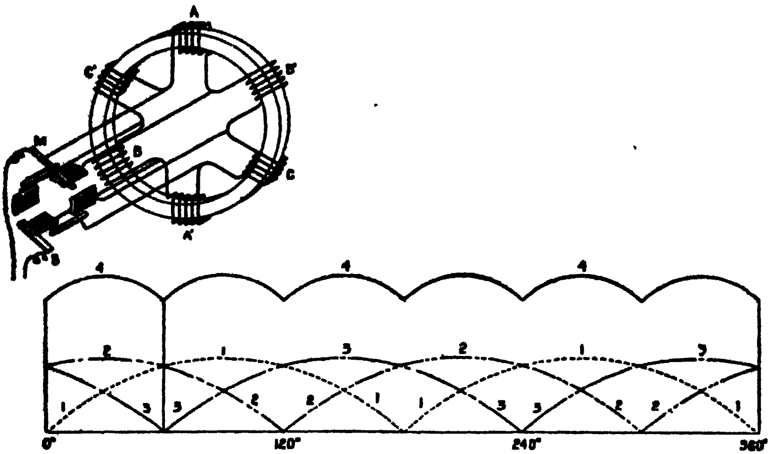


FIGS. 429 and 430.—Gramme ring armature with four coils. The pressure induced in coils A A′, reaches the zero point at the instant that of coils B, B′ is at a maximum; hence, sine curve No. 1, beginning at zero, and No. 2, at the maximum, show the pressure changes for A, A′ and B, B′, respectively. The summation of these curves gives *the resultant curve* No. 3, showing changes in pressure of current delivered to the external circuit.

Ans. *It depends on the number of coils and the manner in which they are connected.*

Comparing curves 1 and 3, in fig. 430, it will be noted that with four coils the variation of pressure or amplitude of the pulsations is less than half that obtained with two; moreover, with four coils the number of pulsations per cycle is doubled.

In order to further observe the approach to continuous current obtained by increasing the number of coils, the effect of a six coil armature is shown in fig. 432, the resultant curve being obtained in the same manner as just explained. For comparison, the curves for the three cases of two, four, and six coils are reproduced under each other in fig. 433.



FIGS. 431 and 432.—Gramme ring armature with six coils. The sine curves 1, 2 and 3, represent the conditions due to coils AA', BB' and CC', respectively, and 4, the resultant pulsations.

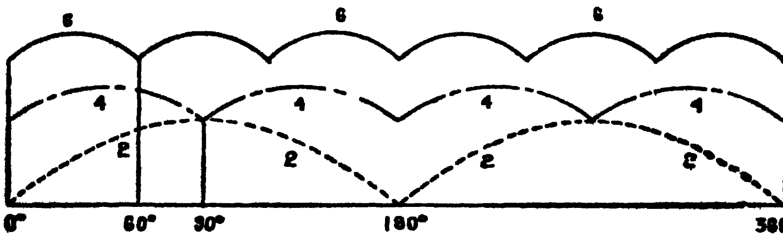


FIG. 433.—The resultant curves of figs. 428, 430 and 432 are here shown for comparison to illustrate the approach to uniform pressure as the number of coils are increased. *It should be noted* that the number of pulsations per cycle depends on the number of coils, and that as the pulsations increase in number, the variation in pressure decreases.

As the number of coils is further increased, the amplitude of the pulsations decreases so that the resultant curve approaches nearer the form of a straight line.

In the actual dynamo there are a great many coils, hence the amplitude of the pulsations is exceedingly small; accordingly, it is customary to speak of the current as "continuous," although as previously mentioned such is not the case.

TEST QUESTIONS

1. *What device is used to obtain direct current in a dynamo?*
2. *What is the construction of a commutator?*
3. *How are the inductors connected to the commutator?*
4. *Explain at length how direct current is obtained in a dynamo?*
5. *What is generally understood by the term "continuous current"?*
6. *How is the so called continuous current produced in a dynamo?*
7. *Upon what condition does the steadiness of the current depend?*

CHAPTER 15

Classes of Dynamo

In order to adapt the dynamo to the varied conditions of service, its design is modified in numerous ways, giving rise to the different "types." These may be classified with respect to:

1. Field magnets;
2. Field excitation;
3. Field winding.

The first division relates to the number of magnetic poles as unipolar, bipolar, and multipolar dynamos; also interpolar dynamos.

Under the second division are included the following:

a. *Self-exciting machines* of which the magneto is the simplest. Its magnetic field is obtained from permanent magnets, hence the voltage generated is comparatively small. The more important type of self-exciting machine is provided with electro-magnets in which the field of force is "built up" from the residual magnetism of the soft iron or steel cores of the field magnets of the dynamo itself. Nearly all commercial types of dynamo are of this class.

b. *Separately excited machines* in which the field magnets are magnetized when the machine is in operation by current supplied from a separate source such as a battery or magneto.

With respect to the third division, based on the field winding, dynamos are classed as:

a. Series wound;

b. Shunt wound.

c. Compound wound.

In addition to the foregoing there are further distinctions with respect to the mechanical features. Most dynamos have a revolving armature and stationary field magnets; however, in some cases, both the armature and field magnets are stationary, a revolving iron conductor being provided to intercept the magnetic lines intermittently which produces the same effect as is obtained in cutting the magnetic lines by a revolving armature.

Ques. What may be said of bipolar and multipolar dynamos?

Ans. Dynamos with bipolar field magnets were universally used prior to 1890, but since that time machines of this type are only made in very small sizes; the multipolar dynamo is the type now in general use.

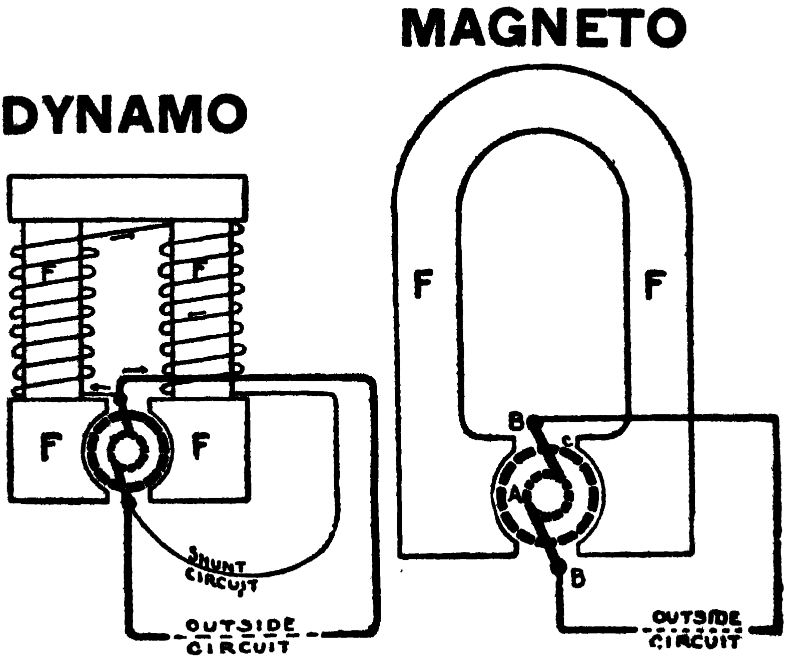
Ques. State some of the features of the multipolar dynamo.

Ans. In this class of machine, the armature and field magnets are surrounded by a circular frame, or *ring yoke* to which the field magnets are attached. This ring arrangement has the advantages of strength, simplicity, symmetrical appearance, and minimum magnetic leakage, since the pole pieces have the least possible surface and the path of the magnetic flux is shorter.

Ques. What important advantage is gained by the use of multi-pole field magnets?

Ans. Commercial voltages are obtained at moderate armature speed.

The difficulty experienced with bipolar machines is that, with a dynamo of large output, the speed at which its armature would have to rotate to generate commercial voltages would be excessive.



FIGS. 434 and 435.—Circuit diagrams to illustrate the difference between a dynamo and a magneto. The dynamo has its field magnets FF, magnetized by means of a small current flowing around a shunt circuit. In a magneto the field magnets are permanently magnetised. The strength of the magnet field of a magneto is constant while that of a dynamo varies with the output.

It is evident that with two or more magnetic fields, secured by increasing the number of poles, the armature inductors revolving between them cut more magnetic lines in one revolution than with a single field, hence, a given voltage is obtained with less speed of the armature than in the bipolar machine.

For instance, if a bipolar dynamo be required to run at say 900 revolutions per minute to generate 125 volts, a four pole machine of equal output will require only 450 revolutions, and one of eight poles only 225 revolutions per minute.

Ques. What is a self-exciting dynamo?

Ans. A machine in which the initial excitation of the field is due to the residual magnetism retained by the cores.

Ques. What may be said of the field due to this residual magnetism?

Ans. It presents a very weak field, and the voltage that could be generated by the armature revolving in such a field would be only about two to ten volts.

Ques. How then can commercial voltages such as 100 or more volts be obtained with a self-exciting dynamo?

Ans. Part or all of the current induced in the armature is passed through the windings of the field magnets, thus strengthening the field. The voltage, therefore, will "build up," increasing until the maximum has been reached.

The maximum voltage will depend upon the capacity of the field magnets as determined by the construction, and upon the strength of current used to excite them.

Ques. How long does the process of "building up" require?

Ans. The time required to fully excite the field magnets is from ten to twenty seconds, the rise in field strength being indicated on the volt meter or by the gradual increase in the brilliancy of the *pilot lamp*.

Ques. Name three important classes of dynamo.

Ans. Series wound, shunt wound, and compound wound.

Ques. Describe the winding of a series dynamo.

Ans. In this machine, the field magnets are wound with a few turns of thick wire joined in series with the armature brushes as shown in fig. 436.

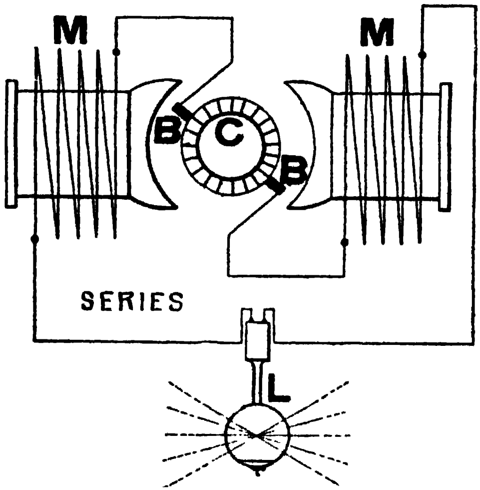


FIG. 436.—Series wound dynamo, used for series arc lighting, and as a booster for increasing the pressure on a feeder carrying current furnished by some other dynamo. *The coils* of the field magnet are in series with those of the armature and external circuit, and consists of a few turns of heavy wire The characteristic of the series dynamo is to furnish current with increasing voltage as the load increases. If overloaded, the voltage will drop.

Ques. What is the effect of this arrangement?

Ans. All of the current generated by the machine passes through the coils of the field magnets to the external circuit.

The current in passing through the field magnets, energizes them and strengthens the weak field due to the residual magnetism of the magnet cores, resulting in the gradual building up of the field.

Ques. For what service is the series dynamo adapted?

Ans. It may be used for series arc lighting, series incandescent lighting, and as a *booster* for increasing the pressure on a feeder carrying current furnished by some other dynamo.

Ques. What is the effect of the series winding in the operation of the machine?

Ans. Its characteristic is to furnish current at an increased

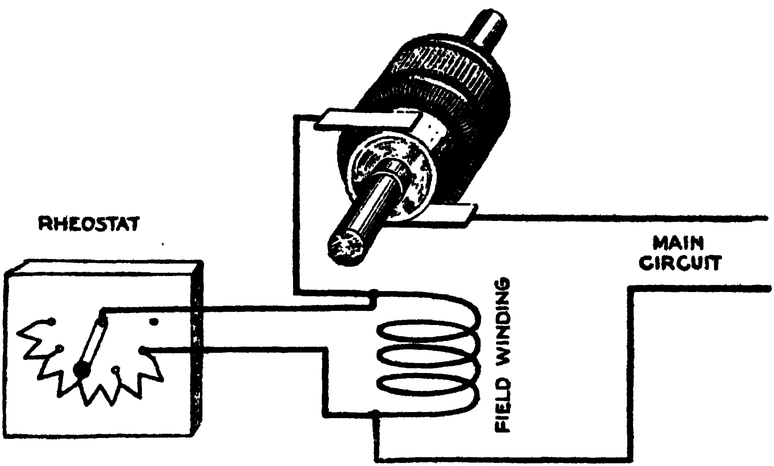


FIG. 437.—The two path method of regulating a series dynamo. The ends of the series winding are connected by a shunt containing a rheostat. The current induced in the armature divides and flows through the two paths thus offered, the amount flowing through the shunt being regulated by the rheostat. In this way the field strength is easily regulated.

voltage as the load increases. If sufficient current be drawn to overload the machine, the voltage will drop.

Since the armature coils, field magnets and external circuits are in series, any increase in the resistance of the external circuit lessens the power of the machine to supply current, because it diminishes the current in the coils of the field magnets and therefore diminishes the effective magnetism.

Again, a decrease in the resistance of the external circuit will increase the voltage because more current will flow through the field magnets. Accordingly, when the external circuit has lamps in series (as is common in an arc light circuit) the switching on of an additional lamp both adds to the resistance of the circuit and diminishes the power of the machine to supply current.

When the lamps are in parallel, the switching on of additional lamps not only diminishes the resistance of the circuit, but causes the field magnets to be further excited by the increased current, so that the greater the number of lamps put on, the greater becomes the risk of inducing too much current.

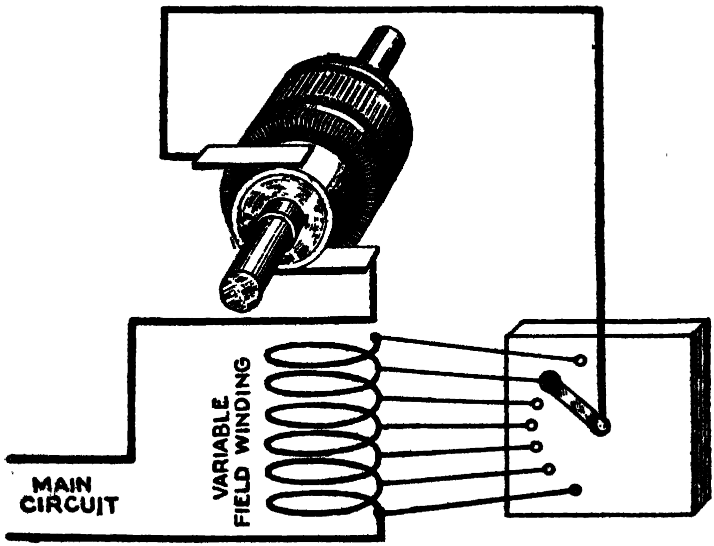


FIG. 438.—Regulation of series dynamo by variable field. A multi-point switch is provided with connections to the field winding at various sections, thus permitting more or less of the field winding to be cut out to regulate its strength.

The series dynamo has also the disadvantage of not starting action until a certain speed has been attained, or unless the resistance of the external circuit be below a certain limit.

Ques. What is the objection to the variable field method of regulation of series dynamos?

Ans. This arrangement is undesirable for magnets of large size, because of the tendency to flashing at the contacts of the regulating switch.

The Shunt Dynamo.—This type dynamo differs from the series wound machine, in that an independent circuit is used for exciting its field magnet.

The field circuit is composed of a large number of turns of fine insulated copper wire, which is wound round the field magnets and connected to the brushes, so as to form a shunt

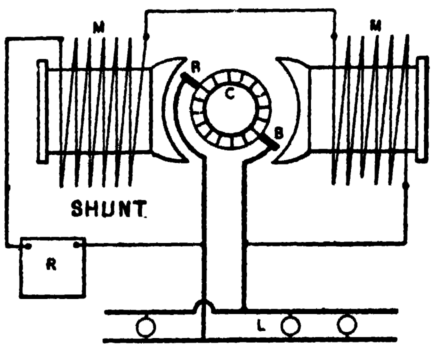


FIG. 439.—Shunt wound dynamo for parallel circuit incandescent lighting, and for mill and factory power. *The coils* of the field magnet form a shunt to the main circuit; they consist of many turns of fine wire and consequently absorb only a small fraction of the current induced in the armature. The characteristic of the shunt dynamo is that it gives practically constant voltage for all loads within its range. If overloaded the pressure will drop and the machine cease to generate current. M, shunt field coils; R, field rheostat.

or "by pass" to the brushes and external circuit, as shown in fig. 439.

Two paths are thus presented to the current as it leaves the armature, between which it divides in the inverse ratio of the resistance. One part of the current flows through the magnetizing coils, and the other portion through the external circuit.

In all well designed shunt dynamos, the resistance of the shunt circuit is always very great, as compared with the resistance of the armature

and external circuit, the strength of the current flowing in the shunt coils being very small even in the largest machines.

Ques. For what service is the shunt dynamo adapted?

Ans. It is used for constant voltage circuits, as in incandescent lighting.

Ques. In the operation of a shunt dynamo what is its characteristic feature?

Ans. The voltage at the dynamo remains pract cally unchanged, and the current varies according to the load.

Ques. Does the voltage remain constant for all loads?

Ans. There is a certain maximum load current that the shunt dynamo is capable of supplying at constant voltage; beyond this, the voltage will decrease, the machine finally demagnetizing itself, and ceasing to generate current.

Ques. Why does the voltage not remain constant for all loads?

Ans. Because there is a drop in the voltage in forcing the current through the armature windings which increases with the load.

Ques. What is the usual method of regulation for shunt dynamos?

Ans. The method of varying the current through the field coils by means of a rheostat inserted in series with the field winding as shown in fig. 439.

Moving the lever of the rheostat to the right increases the resistance in series with the field winding, and this reduces the amount of current

in that winding, thus reducing the strength of the magnet and quently the voltage at the brushes. The contrary movement of the lever, by cutting out the resistance, produces the opposite effect.

The Compound Dynamo.—This type machine is designed to automatically give a better regulation of voltage on constant pressure circuits than is possible with a shunt machine. ***It possesses the characteristics of both the series and shunt machines, of which it is in fact a combination.***

The field magnets of the compound dynamo, as shown in fig. 441,

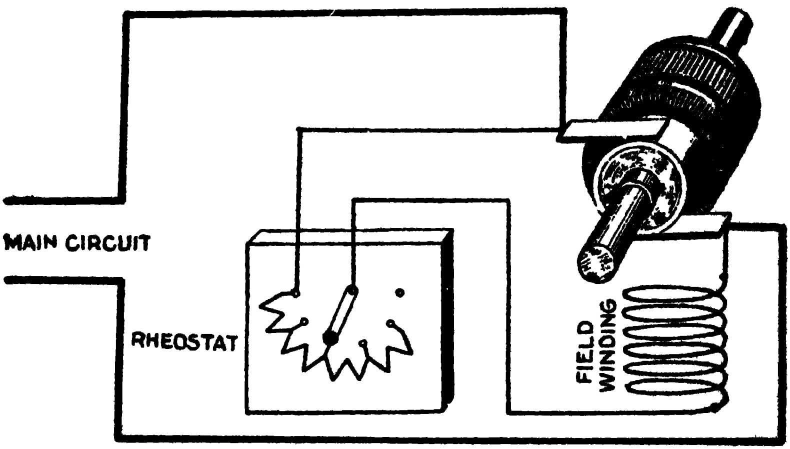


FIG. 440.—Regulation of shunt dynamo by method of varying the field strength. A rheostat is placed in series with the field coils, and by varying the resistance, more or less current will flow through the coils, thus regulating the field strength.

are wound with two sets of coils, one set being connected in series, and the other set in parallel, with the armature and external circuit.

The purpose of the series winding is to strengthen the magnets by the current supplied from the armature to the circuit, and thus automatically sustain the pressure. If the series winding were not present, the pressure at the terminals would fall as the load increased. This fall of

is counteracted by the excitation of the series winding, which increases with the load and causes the pressure to rise.

The number of turns and relative current strengths of the series and shunt windings are so adjusted that the pressure at the terminals is maintained practically constant under varying loads.

With respect to the ratio between the number of turns of the two field windings, the dynamo is spoken of as:

1. Compound;
2. Over compounded.

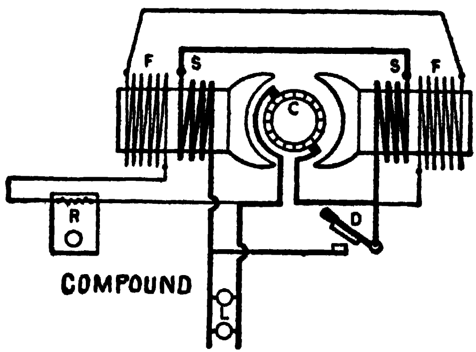


FIG. 441.—Compound wound dynamo, used when better automatic regulation of voltage on constant pressure circuits is desired than is possible with the shunt machine. *The compound dynamo* is a combination of the series and shunt types, that is, the field magnet is excited by both series and shunt windings. With a proper selection of the numb r of turns in the series coils, the voltage may be kept automatically constant for wide fluctuations in the load. When the machine is *over compounded* its characteristic is to slightly increase the voltage with increase of load, a desirable feature for long transmission lines in order to compensate for the line drop.

Ques. What is the difference between a compound and an over compounded dynamo?

Ans. In the first instance, there are just enough turns in the series winding to maintain the voltage constant at the

brushes for variable load. If a greater number of turns be used in the series winding than is required for constant voltage at the brushes for all loads, the voltage will rise as the load is increased, and thus make up for the loss or drop in the transmission lines, so that a constant voltage will be maintained at some distant point from the dynamo. The machine is then said to be *over compounded*.

Ques. For what service is over compounding desirable?

Ans. For incandescent lighting where there is considerable length of transmission lines.

Ques. What is the usual degree of over compounding?

Ans. Generally for a rise of voltage of from five to ten per cent.

In construction, the field coils are wound with a greater number of turns than actually required, the machine being accurately adjusted by a running load test after completion.

Ques. How is the degree of over compounding varied?

Ans. A rheostat is placed in shunt with the series winding so that the current passing through the winding may be regulated to control the voltage of the machine.

Ques. How are the ends of the shunt winding of a com pound dynamo connected?

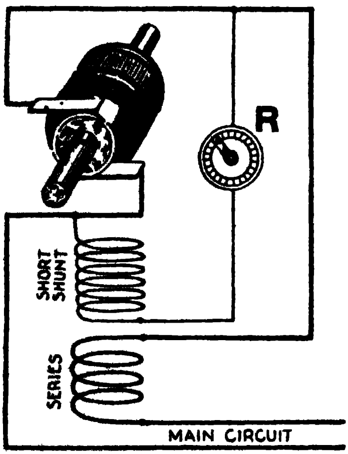
Ans. There are two methods of connection, being known as the short shunt and the long shunt.

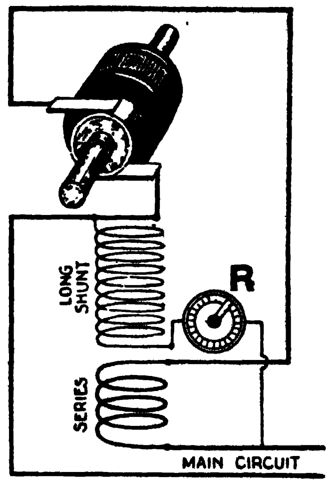
Ques. Describe the short shunt.

Ans. In the short shunt, the ends of the shunt winding are connected directly to the brushes as in fig. 442.

Ques. Describe the long shunt.

Ans. In the long shunt, one end of the shunt winding is connected to one of the brushes and the other end to the terminal connecting the series winding with the external circuit as in fig. 443.





FIGS. 442 and 443.—Short and long shunt types of compound wound dynamos. *The distinction* between the two is that the ends of the short shunt connect direct with the brush terminals, while in the long shunt type, fig. 443, one end of the shunt connects with one brush terminal and the other with the terminal connecting the series winding with the external circuit. R, is the shunt field rheostat for regulating the current through the shunt.

Ques. Which is the more desirable?

Ans. Theoretically, the long shunt is preferable as being the more efficient; however, in practice, the gain is not very appreciable and the short shunt is generally used.

Ques. What may be said regarding the voltage in short, and long shunt machines?

Ans. In a short shunt machine, the shunt winding is subjected to a higher voltage than with a long shunt. The pressure applied through a shunt winding with a long shunt, for any particular load, is equal to the voltage at the brushes plus the drop in the series winding.

Ques. For what other service besides incandescent lighting are compound dynamos adapted?

Ans. They are employed in electric railway power stations where the load is very fluctuating.

Ques. What is the effect of a short circuit on a compound dynamo?

Ans. It overloads the machine, since the excessive current flowing through the series field tends to keep the voltage at its normal value.

Unless the line be automatically opened under such a condition either by a fuse or circuit breaker, the machine and its driving engine may be damaged. To avoid this danger fuses or automatic circuit breakers are employed.

Ques. Mention another service for which the compound dynamo is used.

Ans. In some isolated plants, as small country residences where it is frequently necessary to have a dynamo capable of charging a storage battery during the day, and of furnishing current for lighting during a certain portion of the evening.

Under such conditions the compound machine with slight modification is used. the ordinary shunt dynamo not being capable of maintaining

the necessary consistency of voltage, without attention to the shunt regulator in driving the lamps direct, the ordinary compound dynamo on the other hand, being unsatisfactory for charging storage batteries.

Ques. How is the compound dynamo modified to adapt it to the dual service of lighting and battery charging?

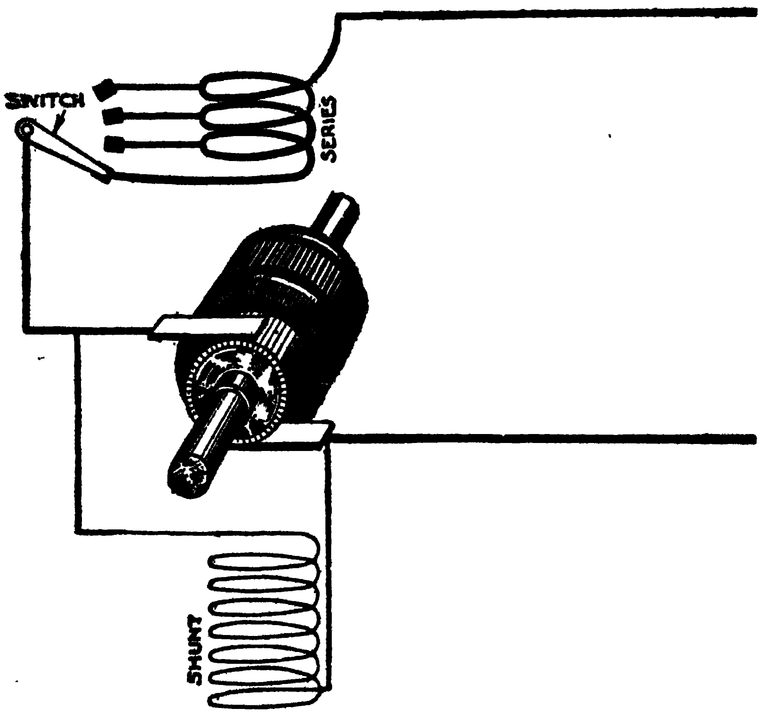


FIG. 444.—Alternative compound winding.

Ans. It is furnished with *alternative compound winding*, in which the series winding is provided with a switch, which may be fixed either upon the machine itself or upon the switchboard.

This switch permits the series coils to be either short circuited in part or cut out of the circuit entirely while the machine is charging the storage battery, being again cut into circuit when the machine is required to furnish current for the lamps.

Separately Excited Dynamos.—In this class of machine *the current required to excite the field magnets is obtained from some independent external source.*

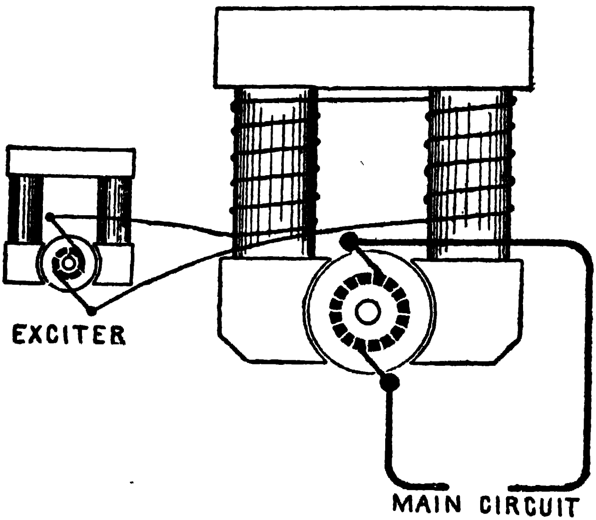


FIG. 445.—Separately excited dynamo. Current for field excitation is supplied by a second and smaller dynamo.

Though used by Faraday, the separately excited dynamo did not come into favor until, in 1866, Wilde employed a small auxiliary magneto machine to furnish current to excite the field magnets of a larger dynamo.

A separately excited dynamo is shown in fig. 445. This method of field

excitation is seldom used except for alternators; it is, however, to be found occasionally in street railway power houses, the shunt fields of all the dynamos being separately excited by one dynamo.

In common with the magneto, the separately excited machine possesses the property that, with the exception of armature reaction, the magnetism in its field and therefore the total voltage of the machine is independent of variations in the load.

Dobrowolsky Three Wire Dynamo.—This type of dynamo was designed to operate a three wire system of distribution

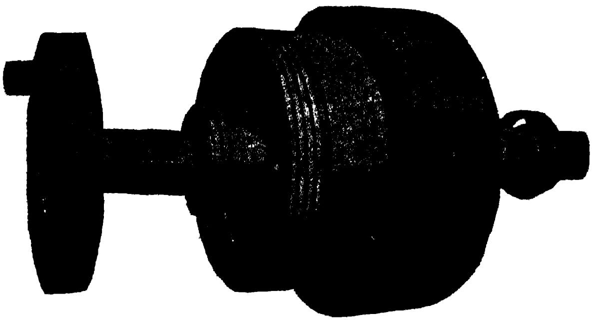


FIG. 446.—Armature of Westinghouse three wire dynamo. Collector rings are mounted at one end of the armature as shown, and the leads to them with the armature winding are similar to those employed on the alternating current side of a rotary converter armature. The connections from the armature to collector rings may be either single phase, two phase, or three phase. The two phase connection with four collector rings and two balance coils is used in the Westinghouse three wire dynamo.

without a balancer. The armature is provided with insulated slip rings connected to suitable points in the armature winding and (by means of brushes) with choking coils meeting at a common point, to which the neutral wire of the system is connected, the main terminals being connected with the outside wires.

The machine is capable of feeding unbalanced loads without serious disturbance of the pressure on either side of the system.

The principle of the Dobrowolski three wire dynamo is illustrated in fig. 447. The armature A is tapped at two points, B and B′, and connected to slip rings CC′. A compensator or reactance coil D, between the two halves of which there is minimum magnetic leakage, is connected to C and C′, by brushes, and has its middle point tapped and connected to the neutral wire E.

It is clear, from the symmetry of the arrangement, that the center point of the coil must always be approximately midway in pressure between that of the brushes, and hence any unbalanced current will return into the armature, dividing equally between the two halves of the coil.

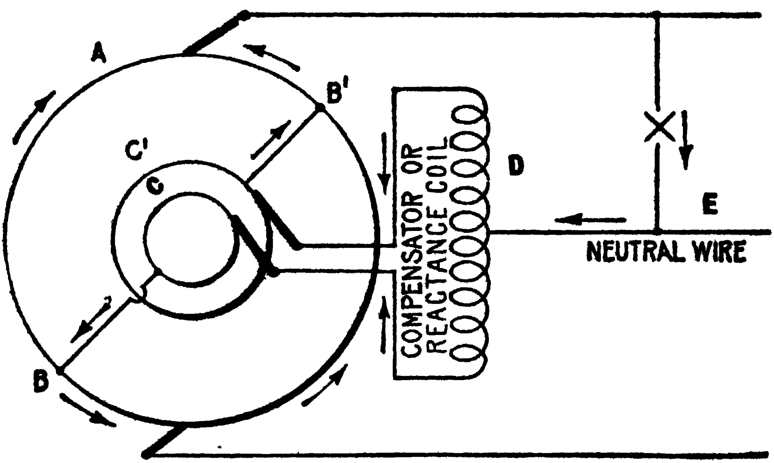


FIG. 447.—Diagram showing principle of Dobrowolski three wire dynamo.

The arrangement forms a cheap and effective substitute for a balancer set, but lacks the adjustable properties of the latter.

There are various modifications of the arrangement. Thus more than two slip rings may be used. The compensator windings, however, should always be arranged so that the magnetizing effect of the neutral current is self-neutralized in the windings, as otherwise saturation occurs causing a very heavy alternating magnetizing component.

TEST QUESTIONS

1. *How are dynamos modified to adapt them to the various conditions of service?*
2. *What is the adaptation of bipolar and multipolar dynamos?*
3. *Mention some features of the multipolar dynamo.*
4. *What is the difficulty experienced with the bipolar machine?*
5. *What is a self-exciting dynamo?*
6. *Is the field due to residual magnetism strong?*
7. *How much voltage could be generated by the residual magnetism?*
8. *How are the high voltages obtained in a self-exciting machine?*
9. *Explain the term "building up."*
10. *Name three important classes of dynamos.*
11. *Describe the winding and operation of series dynamo.*
12. *For what service is the series dynamo adapted?*
13. *Give two methods of regulating a series dynamo.*
14. *What happens if load increases with series dynamo?*
15. *What is the objection to the variable field coil method of regulation?*
16. *Describe the winding and operation of a shunt dynamo.*
17. *For what service is a shunt dynamo adapted?*
18. *How is a shunt dynamo regulated?*
19. *Describe the windings and operation of a compound dynamo.*

20. *What is the difference between a compound and an over compounded dynamo?*
21. *What is the operation of over compounded dynamo?*
22. *What is the usual degree of over compounding?*
23. *What is the difference between the long and the short shunt?*
24. *Is a short or a long shunt subjected to a higher voltage?*
25. *What is the effect of a short circuit on a compound dynamo?*
26. *What is alternative compounding?*
27. *Describe a separately excited dynamo.*
28. *Describe the construction and operation of the Dobrowolski three wire dynamo.*
29. *For what service is the Dobrowolski three wire dynamo adapted?*

CHAPTER 16

Experiments Illustrating Dynamo and Motor Principles

In this chapter a number of simple experiments are shown which will be very helpful to the student in showing in a

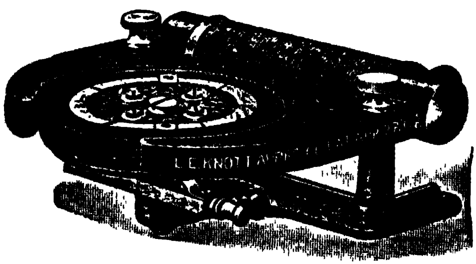


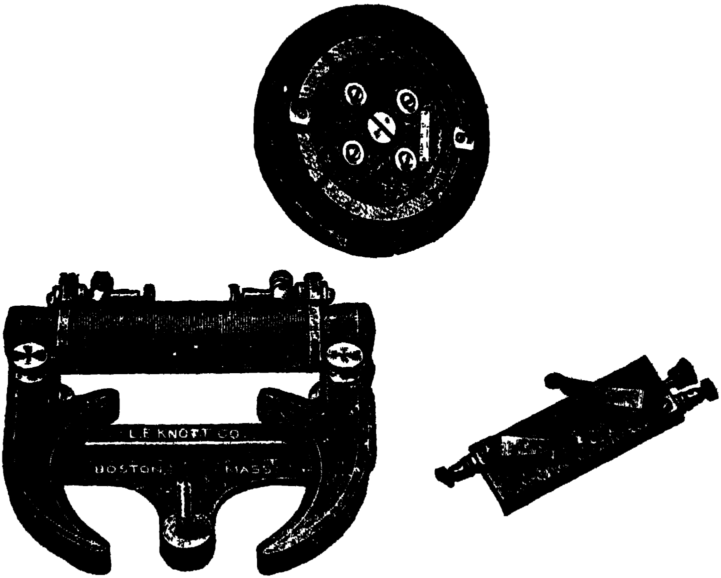
FIG. 448.—Gilley Gramme machine. *Designed to show* the lines of force in a working mode of the dynamo and motor with the armature in position and in actual operation. Both the field and armature are designed and made in flat form, so that the upper surfaces of both are level, permitting the paper or glass upon which the lines of force by the filings method are to be mapped, to take a smooth, horizontal position. The lines of force are thus permitted to arrange themselves under no other influence than that of the magnetic force existing in the armature and field.

simple way "*how it works*." The two elementary machines used in making the experiments are:

1. Gilley Gramme machine;
2. Miller-Cowen Dynamo.

The Gilley-Gramme machine is a modification of a type of machine now generally used for large units for power and lighting stations, so worked out that the lines of force may easily be plotted by the compass and filings methods.

The Miller-Cowen attachment is an outgrowth of the Gilley Gramme machine and was built meeting the requirements of Professors Miller and Cowen of Boston schools. Their purpose was to design a machine of



FIGS. 449 to 451.—Gilley Gramme machine disassembled showing the three basic parts of the apparatus: 1, armature with the commutator; 2, the field magnet with base; 3, the brush holder. The instrument is readily dissected, as the illustrations show. Each part can be studied separately, as will be noted. The four part armature has four segment commutator. The connections of the coils to the commutator segments, being on the under side of the armature, are not shown in the illustration. The field coil is easily removed from its base so designed that 6 in. permanent magnets can be substituted for the field coil, thus teaching the fundamental principle of the magneto.

large open construction, using the same field magnets as are used in the Gilley Gramme machine, and by eliminating the feature of plotting the lines of force by the iron filings method they were enabled to design a machine which could be used in lecture table demonstration and used to

develop all of the fundamental principles of both direct and alternating current machines.

Directions for Experiments with Gilley Gramme Machine.—The following experiments are fundamental. They are the experiments usually selected for secondary school work. Many modifications and additions to this list will suggest themselves to the teacher.

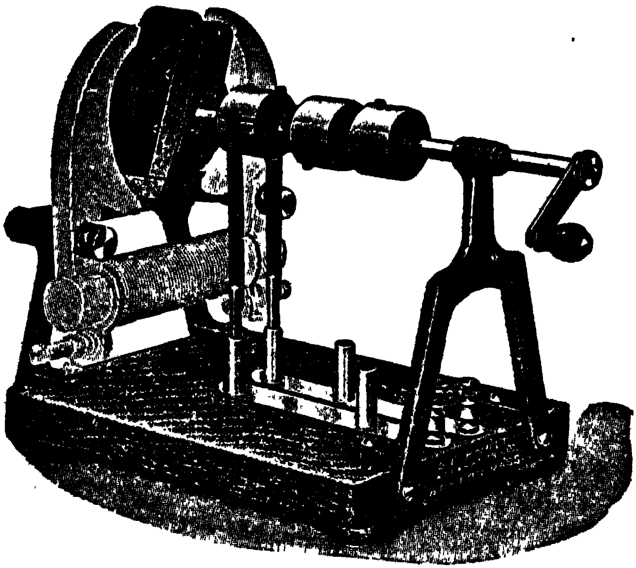
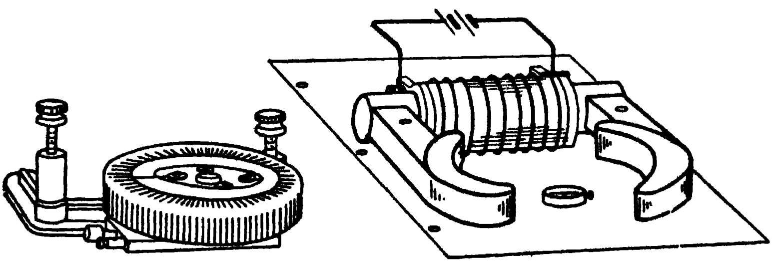


FIG. 452.—Miller-Cowen machine for study of both *d.c.* and *a.c.* In order to enable the student to see clearly the working of the essential parts of the instrument, the split commutator for the direct current and the collecting rings for the alternating current are greatly enlarged and separated from the armature winding. In order to make clear the effect of the iron core in the moving armature, the instrument is designed so that the iron core, which for the sake of efficiency is laminated, is made easily removable, so that the instrument may be used either with or without the core. The field magnet may be easily removed and small permanent magnets clamped under the same screws. The Miller-Cowen machine *serves to demonstrate;* 1, use of commutator; 2, effect of speed of rotation; 3, separately and self excited alternators; 4, series, shunt and compound dynamos. The galvanometer used should not be of high sensibility. Any milli-ampere meter in good working order may be used to

The experiments here described have been compiled by a teacher of long experience in one of the larger Middle West High Schools, the selection and sequence of the work being such as he has found most helpful to his students in developing a clear understanding of the principle and operation of the dynamo and motor.

Exercise 1. Nature of the Field Magnet.

Part 1.—Remove the electromagnet (usually called the field magnet) from the machine and lay it on a page of a note book (fig. 454). Mark its outline on the paper. Connect wires from the poles of a battery to the binding posts and indicate on the paper the direction of the current in



FIGS. 453 to 455.—*Exercise 1.* Gilley Gramme machine with field magnet removed *illustrating the nature of the field magnet.*

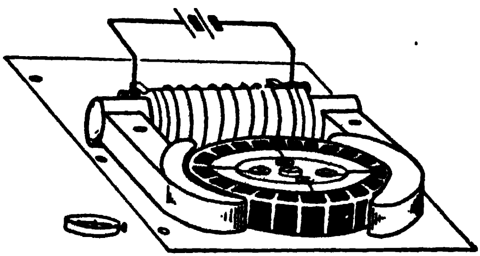
the wires by arrows, remembering that the current is assumed to come from the copper or carbon pole of the battery. Show by an arrow the direction of the current on the top side of the coil. From the direction of the current in the coil determine the North and South poles of the magnet, using Ampere's rule for the purpose. Mark large letters **N** and **S**, on these poles in the diagram.

Now place a small compass between the poles and trace several lines of force in the following way: Place the compass near to one pole piece, and directly under the compass mark the direction in which its North end points. Move the compass ahead in that direction. Mark the direction in which it now points, and so on until the line is traced. Several lines traced in this way, each starting from a different point on the pole piece, will show the distribution of lines in the circular space between the poles

To get an idea of the strength of this field, which has just been mapped, notice how fast the compass needle vibrates after being tipped or jarred when it is between the pole pieces. The stronger the field, the more rapidly the needle vibrates. The field strength is proportional to the square of the number of vibrations per minute.

Part 2.—With the compass still remaining between the poles disconnect the wires from the electromagnet. Notice how fast the compass needle vibrates, and from this compare the strength of the magnetic field when current is and is not flowing through the coil. Notice whether the needle indicates that the iron has retained any of its magnetism. The small amount of magnetism which remains in iron after the current stops flowing is called "residual magnetism."

Part 3.—Again connect the electromagnet with the cell, but this time



FIGS. 456 and 457.—*Exercise 2.* Gilley Gramme machine as connected to illustrate *the effect of iron ring of armature.*

with the current in the coil reversed. With the aid of the compass needle, notice what change has been made in the lines of force.

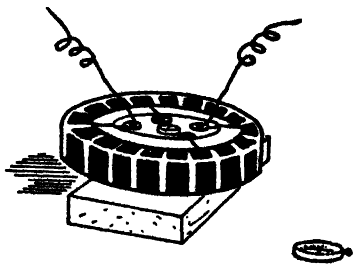
Part 4.—Plot the lines of force by the iron filings method as follows: Having the coil connected with the battery, lay a sheet of note book paper over the pole pieces and sprinkle iron filings until, with gentle tapping, the lines are distinctly formed. Draw a diagram showing the pole pieces and these iron filing lines.

Exercise 2. Effect of Iron Ring of Armature.

Part 1.—Place the armature between the pole pieces of the field magnet as shown in fig. 457. Send current from a cell through the field magnet coil and with the compass needle find what alteration in the lines of force of the field magnet has been made by the presence of the iron ring of the armature.

Part 2.—Plot the lines of force under these new conditions by the iron filings method and make a diagram of field magnet, iron ring and lines of force as shown by the filings. The presence of this iron ring between the pole pieces has changed the shape of the lines of force. Notice also whether the presence of the iron has increased or decreased the strength of the magnetic field between the pole pieces. (Compare this diagram with the diagram in *Part 4* of *Exercise 1.*)

Notice that the compass and the iron filings both indicate no definite lines of force in the space inside of the ring, and that, therefore, when the armature is moving, only that portion of its winding that is on the outside can cut across the lines of force. Consequently, the inside portion of the winding does not help to generate current when the machine is used as a dynamo, nor help to turn the armature when the machine is used as a motor. Partly for this reason armatures of large machines are wound "drum fashion."

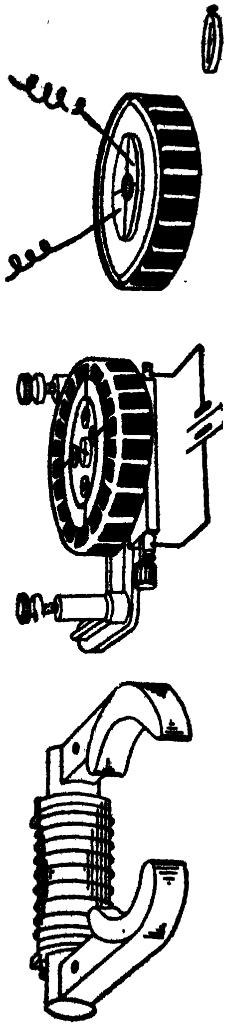


FIGS. 458 and 459.—*Exercise 3.* Gilley Gramme machine armature with nuts uppermost illustrating *the nature of the armature.*

Exercise 3. Nature of the Armature.

Part 1.—Examine the armature. It consists of an iron ring around which there is a continuous winding of wire. At four points on this winding, equally spaced, short wires are soldered on, each of which leads to a nut. Each nut is connected to one of the quarter sectors of brass which comprise the commutator. Set the armature on a shallow box or other support with the four nuts uppermost (fig. 458). Connect the wires from the cell to two diagonally opposite nuts. As these nuts are joined to the sections of the commutator below, this method of connection is the same as if made directly to two opposite sections of the commutator.

Draw a diagram of the ring, the continuous winding (representing only a few turns, evenly distributed), the four wires leading to the nuts, and the battery wires. Trace the paths of the current through the two halves of the winding, and mark this path with a number of arrows on the diagram.



Now test for lines of force with the compass, marking the position of the double North and double South poles. Obtain also the lines of force by the iron filings on a cardboard placed above the armature. Mark these lines on the diagram. This iron ring with its winding is now acting like a double, curved electro-magnet, as shown in the diagram.

Part 2.—Change the cell wires to the other two nuts and see whether the armature is still a double electro-magnet. Notice where the poles are situated with reference to their position in *Part 1* preceding. Observe in both *Part 1* and *Part 2* where the poles are situated with reference to the places where the current enters and leaves the coil. It will be seen that there are only two separate currents in the armature and that these are in parallel with each other.

Exercise 4. What the Commutator Does.

Part 1.—Remove the field magnet and place the armature on its pivotal bearing as shown in fig. 461. Send current through the armature winding by connecting the cell wires to the binding posts which lead to the brushes.

Move a compass around outside of the armature and find a place where the compass needle points in a line with the center of the armature. The compass is now at one of the poles of the armature. Rest the compass on some convenient support in this position and on a level with the armature. Begin turning the armature slowly and keep watch of the compass.

Stop the armature at the exact point where the needle makes a sudden jump.

Look at the commutator and see whether the brushes slide from one section to another at that instant. Turn the armature through one complete revolution and find how many times the jumping of the needle indicates that the poles of the armature shift.

Figs. 460 to 463.—*Exercise 4.* Gilley Gramme machine disassembled illustrating *what the commutator does.*

While the armature is being rotated notice whether the North pole of the armature stays on one side of the armature or shifts to the opposite side.

Part 2.—Remove the armature and lay it down with the commutator on the upper side. Place the compass near it, and by taking the cell terminals as shown in fig. 462, in the hands, attempt to verify the facts just found in *Part 1*. In doing this, keep the commutator still but move the cell wires just as if they were the brushes, always keeping them in contact with opposite, not adjacent, sections of the commutator.

Exercise 5. Why the Armature of a Motor Rotates.

Part 1.—Send current from the cell through the field magnet winding by connecting it as shown in fig. 464. Test the poles of the magnet with the compass. Draw a diagram of the field magnet and mark on it the

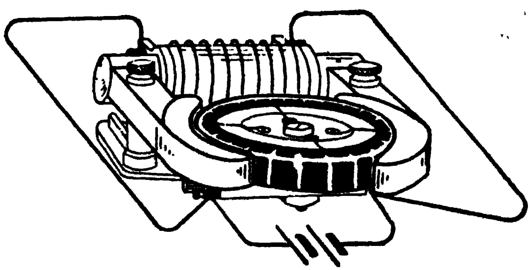


FIG. 464.—*Exercise 5.* Gilley Gramme machine as connected to illustrate *why the armature of a motor rotates.*

poles as indicated by the compass and mark with a plus (+) sign the binding post by which the current enters the field coil.

Part 2.—Send current from the cell through the armature winding by connecting it as shown in fig. 461. Turn the brush holder until the points of the brushes that touch the commutator are in a line parallel to the two arms of the field magnet (when the latter is in position). Test with the compass and mark the poles of the armature on the diagram made for *Part 1*.

Put a plus sign on the diagram near the binding post by which the current enters the armature winding. From a study of the diagram thus made, assuming that currents were to flow simultaneously in both the field and the armature in the directions indicated, decide and mark on the diagram the direction in which the North pole of the armature would begin to turn.

Part 3.—Place both armature and field magnet on the stand and make the connections shown in fig. 464, being sure that the current flows in the armature and in the field magnet in the same direction that it did in *Parts 1* and *2* of this exercise. Notice whether the armature rotate in the direction to be expected from *Part 2*. Make a new diagram of the connections showing the direction of the current by arrows, mark the poles of the field, the poles of the armature and mark the direction of rotation of the armature.

Part 4.—Turn the brush holder through 180° or half circle, and notice that the armature rotates in the opposite direction. On a new diagram show whether the direction of the current has been thus reversed in the armature or field or both, and explain why the direction of rotation has changed. While the armature is turning or held stationary, but while the current is still flowing, place a sheet of smooth cardboard over the machine and sprinkle iron filings upon it. Compare the lines of force

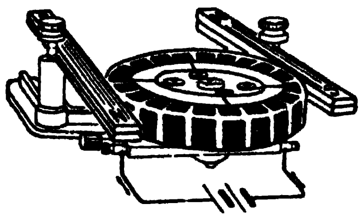


FIG. 465.—*Exercise 6.* Gilley Gramme machine as connected to illustrate *a magneto used as a motor.*

with those obtained in *Exercise 2.* Observe whether the armature rotates in the direction to be expected if the lines of force were stretched elastic threads.

Part 5.—Turn the brush holder through 90° and explain why there is no tendency for the armature to rotate.

Exercise 6. The Magneto Machine as a Motor.

Remove the field magnet and connect the battery directly with the brush holder. Have the latter in the proper position for rotation of the armature. Put one or more strong, permanent magnets in the place of the field magnet, arranging them as shown in fig. 465. (If two magnets be used to form one stronger magnet they should have like poles in contact with each other.) Notice that the motor is now operating with *permanent* magnets to provide the magnetic field instead of with the

electro-magnet used in *Exercise 5*. The principal difference is that the electro-magnet is the stronger. Curved pole pieces may be used with either kind. Permanent field magnets are never used in large practical machines. *Why?*

Exercise 7. The Dynamo.

Part 1.—The magneto machine operated as a motor in *Exercise 6* when it was supplied with a current from a battery. In order to use the same machine as a dynamo no battery is needed. Make the connections shown in fig. 466, in which the galvanometer is used merely to indicate whether the machine is generating a current of electricity. Adjust the galvanometer properly for use. Then rotate the armature by hand in the same direction in which it was rotating in *Exercise 6*.

Observe that the galvanometer indicates that a current of electricity is being produced in the rotating armature. Notice whether this current

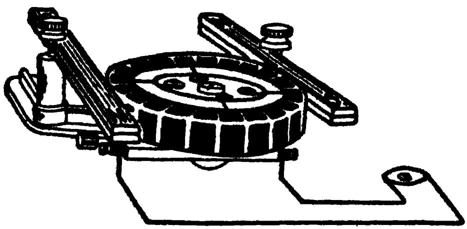


FIG. 466.—*Exercise 7.* Gilley Gramme machine as connected to illustrate *for producing current.*

is always of the same strength and whether it is always in the same direction. Compare the direction of this induced current in the armature* with the direction in *Exercise 6*.

Part 2.—Replace the permanent magnets by the electro-magnet and connect the latter with the cell as shown in fig. 467. Rotate the armature by hand and notice the evidence which the galvanometer gives of a

*NOTE.—In order to tell which way the current is flowing, it is necessary to notice whether the zero of the D'Arsonval galvanometer is deflected to right or left. Then by sending a very weak current, the direction of which is known, into the galvanometer and noting the deflection caused by the known current the direction of the unknown current may be found.

current which is being produced in the armature. Rotate the armature very slowly, then more rapidly, and compare the strength of the current obtained under these conditions.

The machine is now being operated as a dynamo; that is, the result of rotating the armature by some mechanical means is the production of a current in the armature. In commercial machines, the current generated in the armature may be many times greater than the current needed to excite the field magnet. When the field magnet is excited by a current from some outside source (such as the battery in this case) the dynamo is said to be *separately excited*.

Part 3.—Without removing the field magnet, disconnect it from the battery, remembering that there may be a small amount of residual magnetism left now in the iron core of the field magnet (see *Exercise 1*).

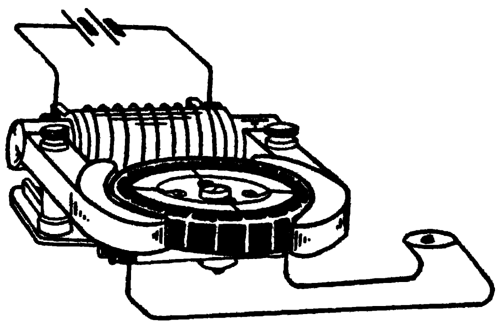


Fig. 407.—Exercise 7--Part 2. Gilley Gramme machine as connected to illustrate *a separately excited dynamo.*

Try rotating the armature to see if a current of electricity is induced in the armature. "Building Up." *In commercial machines there is always more or less residual magnetism in the iron of the field magnet.* Under these conditions if the armature be made to revolve rapidly, a very weak current will be generated in the armature. If this weak current be passed through the coil of the field magnet, the latter becomes a stronger magnet than before.

For this reason the current in the armature grows stronger, and this stronger current in passing through the field coil, will consequently produce a still stronger field magnet. This process of mutual "building up" goes on until a maximum is reached, when the iron of the field magnet is saturated and carries all the lines of force it can. *Such a dynamo is self-exciting*, because it provides its own current for exciting its field magnet.

Most commercial dynamos are self-exciting. Alternators are separately excited by a small dynamo.

Exercise 8. Series and Shunt Motors.

Part 1.—Make the proper connections to operate the machine with the armature in series with the field magnet coil. Notice the direction of rotation of the armature. Reverse the connections at the battery. Explain why there is no reversal of the direction of rotation; also how to change the connections in order to have the armature rotate in the opposite direction. (See ***Exercise 5*** for a suggestion, but there is also another method.)

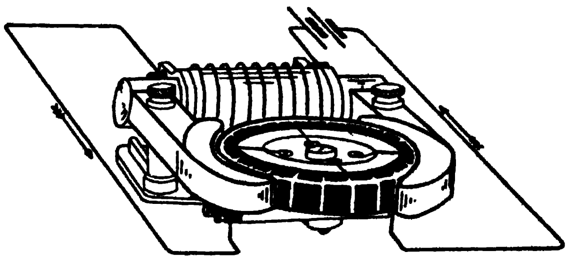


FIG. 468.—*Exercise 8.* Gilley Gramme machine as connected to illustrate *series and shunt motors.*

Part 2.—Make the proper connections to operate the machine with the armature in shunt with the field magnet coil. Make a diagram of these connections. Notice the direction of rotation of the armature. (Use two cells in series if necessary.) Reverse the connections at the battery. Explain why there is no reversal of the direction of rotation. Consider whether this shunt machine may have the direction of rotation of the armature reversed by a proper change of connections.

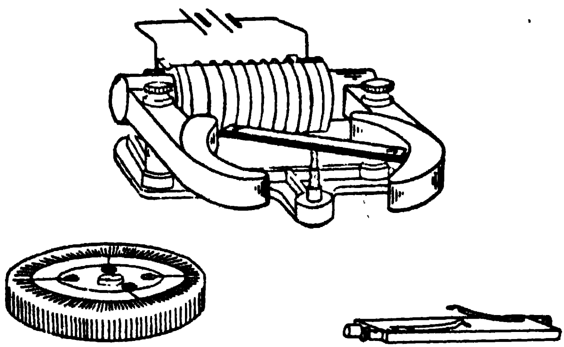
Exercise 9. A Problem on Rotation.

Remove the armature and place a bar magnet on the pivot as shown in fig. 469 so that it may revolve between the pole pieces of the field magnet. Turn on the current in the field winding. Observe the behavior of the magnet when this is repeated several times and consider one reason why an electro-magnet is more advantageous than a permanent magnet for an armature.

Consider a possible method of making the magnet rotate always in the same direction by changing the direction of the current in the field winding.

In order to accomplish this, the reversal of the current must be made when the magnet is in a certain position. Decide what that position is. How many reversals of the current would be needed during one complete revolution of the magnet?

Experiments with the Miller-Cowen Dynamo.— Before commencing the work outlined below, study the instrument itself. Note the relation of the different parts to the whole.



FIGS. 469 to 471.—Gilley Gramme machine with armature replaced by a bar magnet illustrating *a problem on rotation.*

Trace the electrical circuit from the armature coil through the split commutator or collecting rings to the brushes and binding posts.

The rings and sections of commutator should be clean and it is well to occasionally polish them with sand paper as imperfect contact with the brushes would give poor results, especially in the experiments in which the iron is left out of the armature since the voltage generated is small. The galvanometer used should not be of high sensibility. Any milli-amperemeter in good working order may be used to

advantage. A lecture table galvanometer having a suitable range for the work should be used.

Experiment 1.—Remove the laminated iron core from the armature coil. Connect one cell or battery to the field winding; attach brushes so that they will make contact with the collecting rings; connect a galvanometer of rather low resistance and sensibility across the brushes (as shown in fig. 472).

Turn the armature coil slowly. Note movement of the galvanometer needle. Does the needle move continuously in one direction or does it move first in one direction then in the reverse direction? Note relation of armature coil to the field magnet at time of change.

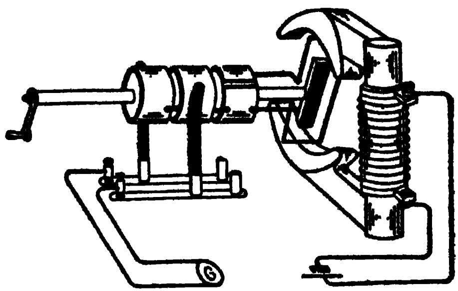


FIG. 472.—Miller-Cowen dynamo *as connected for experiment 1.*

Turn the armature coil sharply one quarter turn in one direction and note movement of galvanometer needle.

Move armature coil back to original position by another sharp turn. Test the polarity of both poles of field magnet and of both ends of the armature coil just before and just after it passes the point where a change of current direction is indicated by the galvanometer needle. What connection is there between change of polarity in the armature coil and change of direction in the current? Why is the current produced called an alternating current?

Experiment 2.—Replace the laminated iron core in the armature coil Follow same steps as before. What effect has iron in the armature coil upon strength of current?

Experiment 3.—Attach brushes so that they make contact with the commutator (as shown in fig. 473). Turn armature at a moderate speed. Observe the movement of the galvanometer needle. How is this current different from that observed above? Why is it known as a direct current?

Experiment 4.—Describe the commutator. Note how it is connected to the armature coil and its relation to the brushes as the armature coil is rotated. Rotate the armature coil slowly and test the polarity of the ends as the brush contact changes on segments of the commutator. What is the office of the commutator? Describe action completely.

Experiment 5.—Rotate armature coil at different speeds. What is the effect of speed of rotation on strength of current?

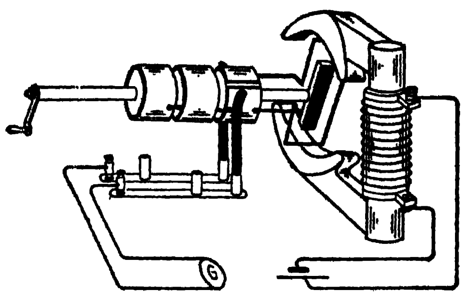


Fig. 473.—Miller-Cowen dynamo *as connected for experiment 3.*

Experiment 6.—Note that in figs. 472 and 473 the armature coil is not electrically connected with the field coil. Why would apparatus of this class be known as separately excited dynamos?

Experiment 7.—How do the connections of figs. 474 to 476 differ from those of figs. 472 and 473? Why is the battery unnecessary? Your conclusion should give you the definition of a *self-excited dynamo.* Why are many large alternators of the separately excited type? Why are practically all dynamos self-excited?

Experiment 8.—Connect the apparatus as in fig. 475. How is the field coil excited? What form of connection is this? Why does such an arrangement show a shunt dynamo? What effect has this winding upon flow of current generated?

Experiment 9.—Connect apparatus as in fig. 474. How is the field excited? What form of connection is this? Why does such an arrangement show a series dynamo? What effect has this winding upon flow of current produced?

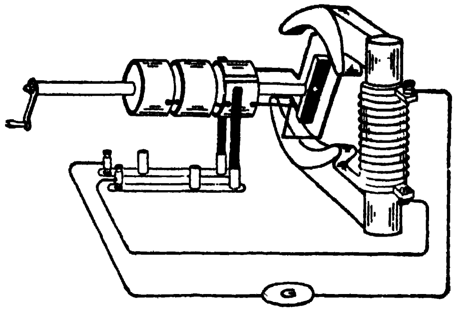


Fig. 474.—Miller-Cowen dynamo *as connected for experiments 7 and 9.*

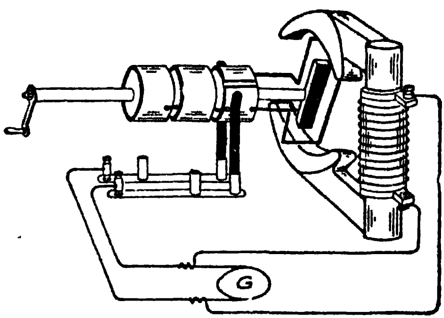


Fig. 475.—Miller-Cowen dynamo *as connected for experiment 8.*

Experiment 10.—Wind a few turns of wire about the field coil and connect the apparatus as in fig. 476. How is the field excited? Why does such an arrangement show a compound wound dynamo? What effect has this winding upon flow of current generated? A well designed dynamo of the shunt, series, or compound type will usually operate as a motor when connected to a source of electrical energy having sufficient power. Its speed of rotation will be fixed, for in rotating, the armature generates a

current the same as though it were turned mechanically. This generated current is always opposed to the direction of current flow from the outside source.

A constant point will therefore be reached in which the current generated by the moving armature plus the energy wasted in keeping up rotation plus friction, etc., balance the pressure of the current flow from the outside source.

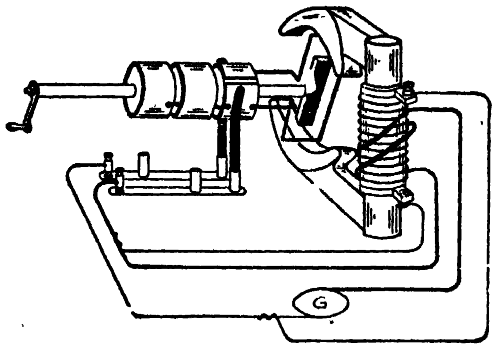


FIG. 476.—Miller-Cowen dynamo connected as a *compound* machine *experiment 10.*

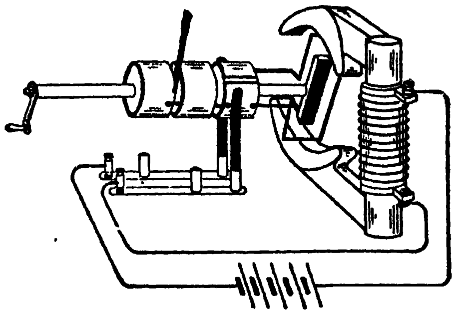


FIG. 477.—Miller-Cowen dynamo connected *to run as a motor experiment 11.*

Experiment 11.—The apparatus connected as in fig. 477 shows the dynamo run as a motor. Explain the operation. What is the direction of the current flow from the outside source? Disconnect and determine the direction of current flow when the armature is turned by hand. Are these currents opposed to each other or do they flow in the same direction? What effect would this have on the rotation of the armature?

TEST QUESTIONS

1. *What is the object of the experiments made in this chapter?*
2. *Describe the Gilley Gramme machine.*
3. *Demonstrate with the machine: 1, nature of the field magnet; 2, effect of iron ring of armature; 3, nature of the armature; 4, what the armature does; 5, why the armature of a motor rotates; 6, the magneto machine as a motor; 7, the dynamo; 8, series and shunt motors; 9, a problem on rotation.*
4. *Demonstrate with the Miller Cowen dynamo: 1, change of polarity in the armature; 2, effect of iron on the armature coil; 3, direct current; 4, office of the commutator; 5, effect of speed of rotation; 6, separately excited dynamo; 7, self excited dynamo; 8, series dynamo; 9, effect of series winding; 10, compound wound dynamo; 11, dynamo run as a motor.*

CHAPTER 17

Field Magnets

The object of the field magnet is *to produce an intense magnetic field within which the armature revolves.*

It is constructed in various forms, due in a large measure to considerations of economy, and also to the special conditions under which the machine is required to work.

Electro-magnets are generally used in place of permanent magnets on account of:

1. The greater magnetic effect obtained, and
2. The ability to regulate the strength of the magnetic field by suitably adjusting the strength of the magnetizing current flowing through the magnet coils.

The field magnet, in addition to furnishing the magnetic field, has to do duty as a framework which often involves considerations other than those respecting maximum economy.

The Make Up of a Field Magnet.—In construction, the electro-magnet, used for creating a field in which the armature of a dynamo revolves, consists of four parts:

1. Yoke,
2. Cores,

3. Pole pieces;
4. Coils.

These are shown assembled in figs. 478 to 481.

Ques. What is the object of the yoke?

Ans. The yoke serves to connect the two "limbs," that is, the cores and pole pieces, and thus provide a continuous metallic circuit up to the faces of the pole pieces.

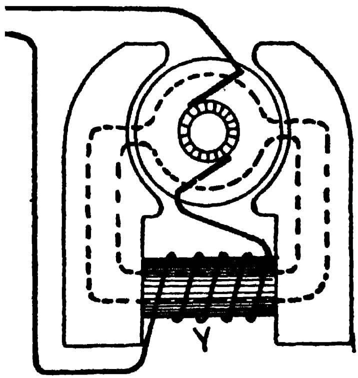


FIG. 478.—Salient pole, bipolar field magnet with single coil wound around the yoke.

Ques. How is the yoke constructed?

Ans. It usually forms the frame of the dynamo as shown in figs. 482 and 483.

Ques. What may be said of the cores?

Ans. The cores, which are usually of circular form, carry the coils of insulated wire used to excite the magnets.

Classes of Field Magnet.—Although numerous forms of

field magnet have been devised, they can be classed into two groups according to the type of pole, as:

1. Salient pole;
2. Consequent pole.

The distinction between these two types of pole is shown in figs. 478

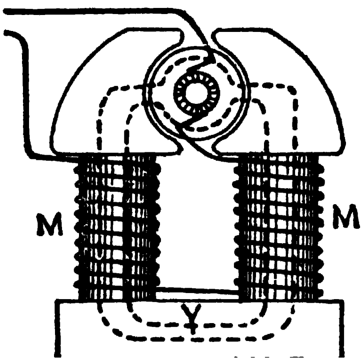


FIG. 479.—Salient pole, bipolar field magnet with two coils wound around the cores.

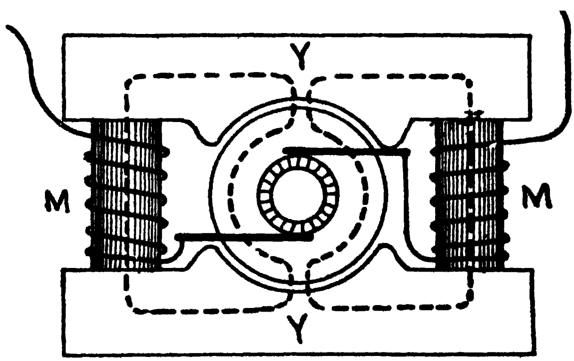


FIG. 480.—Consequent pole bipolar field magnet with two coils on the cores. This is known as the "Manchester" type in which the cores are connected at the ends by two yokes—so named from its original place of manufacture at Manchester, England.

to 480. By inspection of the figures, it will be seen that the term *salient* applies to poles produced when the pole pieces form the *ends* of the magnet, as distinguished from *consequent* poles, or those formed by coils wound on a continuous metal ring or equivalent.

In the salient pole bipolar magnet, the winding may be either upon the limbs, MM, fig. 479, or upon the yoke, Y, as shown in fig. 478. The magnetic circuit of salient and consequent poles is indicated in the figures by the dotted lines.

Multi-Polar Field Magnets.—In the multi-polar machine,

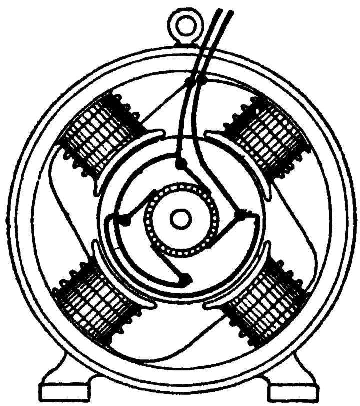


FIG. 481.—Modern dynamo with four consequent pole field magnets. In this construction the ring shaped yoke also serves as a frame; the circular form of yoke gives the least chance for magnetic leakage.

the subdivision of the magnetic flux reduces the amount of material of both magnet and armature. Moreover, there is less heating on account of the greater capability of dissipating the heat, offered by the increased area of surface per unit of volume in each magnet pole and winding.

There may be four, six, eight, or more poles, arranged in alternate order around the armature. Fig. 481 shows a four pole field magnet having a common yoke or iron ring, with four pole pieces projecting inwardly, and over which the exciting coils are slipped.

In the larger machines the yoke is made in two parts bolted together as shown in fig. 483, so that the upper portion may be lifted off for examination of the armature.

Ques. Can the number of poles in a multi-polar machine be advantageously increased to 16, 32, or more?

Ans. A large number of poles is not advisable except in very large machines, since it involves an increase in the expense of machine work, fittings, etc., somewhat out of proportion to the reduction in cost of material and increase in efficiency.

Ques. What materials are generally used for field magnets?

Ans. Wrought iron, cast iron, steel and copper.

There are a number of considerations which govern the selection of the materials to be used in a particular machine, such as initial cost, weight, efficiency, etc.

Ques. In the construction of field magnets, what governs the choice of materials?

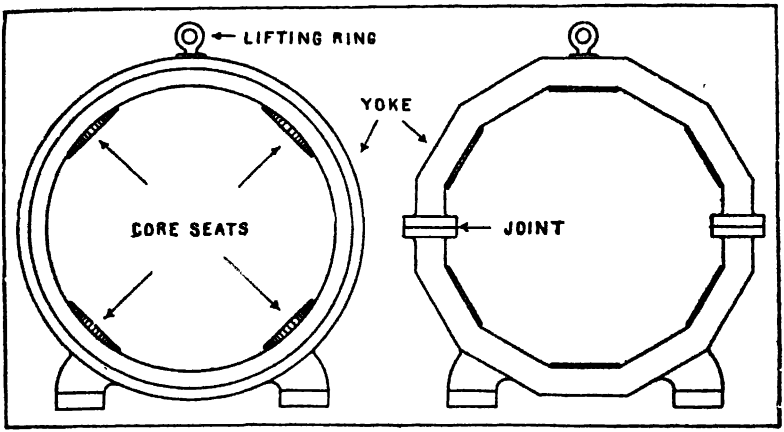
Ans. For cores, wrought iron is most desirable, as requiring the smallest amount of material for a given flux. There is a saving in copper due to using wrought iron for the core since, on account of its small size, the length of each turn of the magnetizing coil is reduced. For heavy yokes, where lightness is not essential, but very often the reverse, cast iron is used, as its cross section can be made larger than that of the cores, this increase in area serving to give strength and rigidity to the machine. Cast steel occupies a place intermediate between cast iron and wrought iron both in cost and magnetic properties.

Ques. Name two forms of yoke in general use.

Ans. The solid, and divided types as shown in figs. 482 and 483.

Ques. What is the object of dividing a yoke?

Ans. To permit access to the armature, where the construction does not admit of removal of the latter from the side.



FIGS. 482 and 483.—Solid and split construction of yoke for multi-polar dynamos. *In the latter type,* the yoke is in two halves joined along a horizontal diameter; while the upper half may be conveniently removed to give access to the armature. It has the disadvantages of the joint, which, no matter how well made, will add to the reluctance of the magnetic circuit. The figures also illustrate the circular and segmental forms of yoke construction.

Ques. How is the yoke usually divided?

Ans. Across its horizontal diameter into an upper and lower half, as shown in fig. 483, the lower half being seated on, or more frequently cast in one piece with the bed plate.

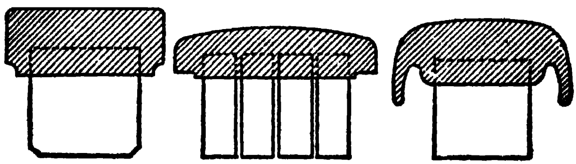
Ques. What is the objection to dividing a yoke?

Ans. The joints introduced, even if carefully faced and

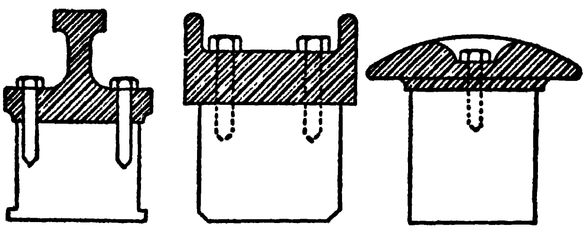
well bolted together, add a little reluctance to the magnetic circuit.

Ques. How does this affect the poles adjacent to the points, and what provision is made?

Ans. It weakens them, and in order to overcome this, the coils of these poles are given a few extra turns.



Figs. 484 to 486.—Various sections of cast iron yoke. *In form*, these yokes may be either circular or segmental as shown in figs. 482 and 483.



Figs. 487 to 489.—Various sections of cast steel yoke. The ribs shown in figs. 487 and 488 are provided to secure stiffness.

Ques. How is the reluctance of a yoke joint reduced?

Ans. By enlarging the area of contact; the flange for the bolts furnishes the necessary increase.

Ques. What determines chiefly the cost of field magnets?

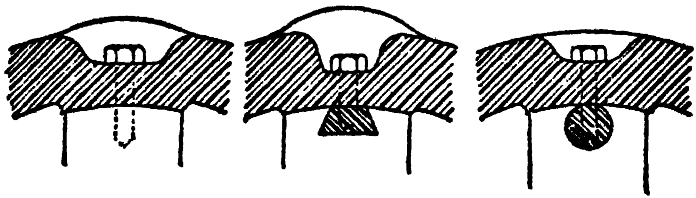
Ans. The material used in making the cores and their shape.

Ques. How does this affect the cost?

Ans. Since considerable cross sectional area of core is required, the problem confronting the designer is to design the core by judicious selection of material and shape, that the required number of turns in the magnetizing coil is obtained with the shortest length of wire.

Ques. What is the principal objection to the use of cast iron for core construction?

Ans. Since its sectional area must be considerably more



Figs. 490 to 492.—Some methods of attaching detachable cores. *The core seat* is machined to receive the core, it being necessary to secure good contact in order to avoid a large increase in the reluctance of the magnetic circuit.

than wrought iron, a much greater quantity of copper is required for the magnetizing coils.

Copper is expensive, while cast iron cores are less expensive than equivalent ones of wrought iron; in this connection, it is interesting to observe how different designers aim at true economy in construction.

Steel is sometimes used in place of wrought iron, and though less efficient magnetically, it can be cast into the desired shape, thus avoiding the somewhat expensive processes of forging and machining, which are necessary in the case of wrought iron.

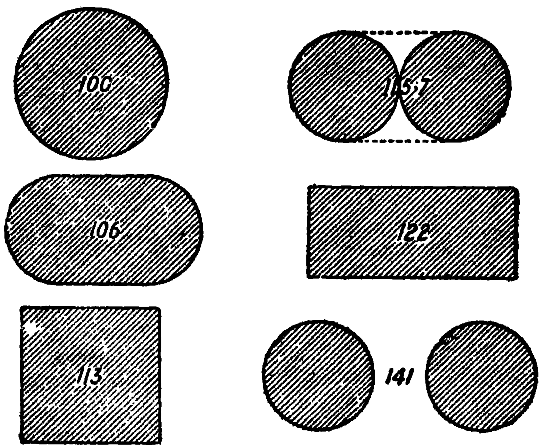
Ques. What form of core requires the least amount of copper for the magnetizing coils, and why?

Ans. The cylindrical core, because it has the shortest periphery or boundary for a given area enclosed.

Figs. 493 to 498, show a series of cross sections, all of the same area. The number marked on each section indicates the length of the boundary line, that of the circle being taken for convenience as 100.

Ques. What are the pole pieces?

Ans. These are the end portions of the field magnets, joined to, or cast together with the core and placed adjacent to the armature.



FIGS. 493 to 498.—Comparison of field magnet core sections. *The shorter* the perimeter or outside boundary of the core for a given cross sectional area, the less will be the amount of copper required for the magnetizing coils. All the above sections are of equal area, and the figures marked on each represent relative values for the perimeters, the circle for convenience being taken at 100.

The faces of the pole pieces are of circular shape, thus forming the sides of the so called armature chamber within which the armature rotates.

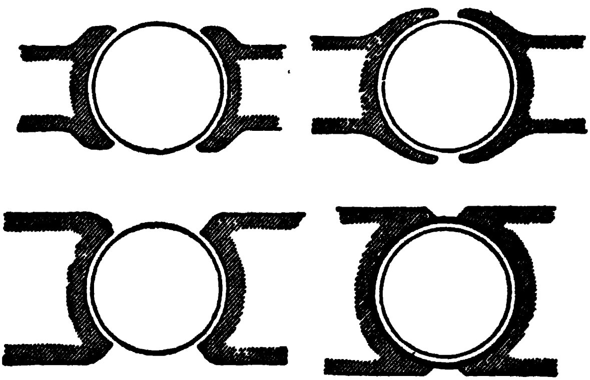
Ques. Why are the pole faces made larger than the coils?

Ans. In order to reduce the reluctance of the air gap between

the face and the armature, thus enabling fewer magnetizing coils to be used.

It is important that the field should be magnetically rigid, that is, not easily distorted. This stiffness of field can be partially secured by judicious shaping of the pole pieces. A few forms of pole piece are shown in figs. 512 to 514.

If the projecting tips of the pole pieces, or *horns* as they are called, be widely separated, as in fig. 499, they are not always good, even though thin. It is better that they should be extended as in fig. 500 so that they may be saturated by the leakage field or else cut off as in fig. 501.



FIGS. 499 to 502.—Several forms of pole piece. Where the extremities project as in figs. 499 and 500, they are called *horns*. The object of these is to reduce the reluctance of the air gap. The width of "fringe" of the magnetic field is influenced by the shape of the pole piece; the margin of fringe should be such that the flux density will vary from zero to a high value where the inductors enter.

An extreme design, suggested by Dobrowolsky, as shown in fig. 502, surrounds the armature with iron.

Another scheme, proposed by Gravier, employed the unsymmetrical form shown in fig. 503. In this pole piece the forward horn is elongated. The action due to this arrangement is such that when the machine is working at small loads, the field in the gap is nearly uniform, but at heavy loads with distorting reactions which have a tendency to drive the flux into the forward horn, the small section of the latter causes it to become saturated, thus reducing the distortion to a minimum.

Eddy Currents, Laminated Fields.—The field magnet cores and pole pieces, as well as the armature of a dynamo are specially

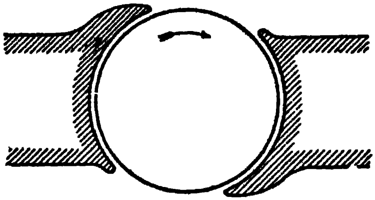


FIG. 503.—Unsymmetrical pole piece introduced by Gravier to concentrate the magnetic field. When the dynamo is working at small loads, the flux in the gap is nearly uniform, but at heavy loads, the distortion due to the armature current forces the flux forward and saturates the forward horn, thus preventing much change in its flux density, on account of the saturation, and the diminishing area. Lundell combined the unsymmetrical and slotted forms of pole piece as shown in fig. 516.

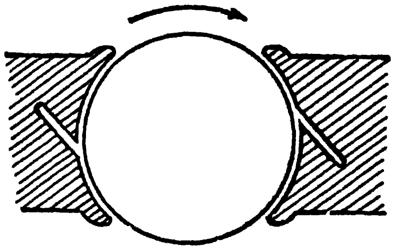


FIG. 504.—Pole piece with oblique slots; a modification of Lundell's form of pole piece as suggested by Thompson. *In operation,* the neck of the casting becomes saturated and offers considerable reluctance, which tends to prevent distortion of the magnetic field.

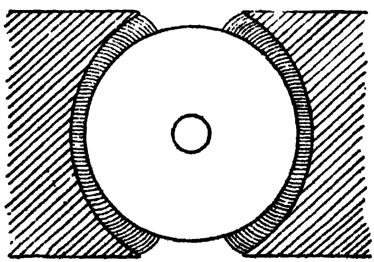
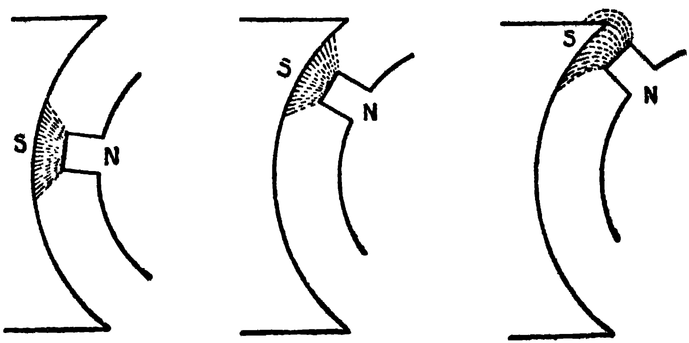


FIG. 505.—Non-concentric pole faces; one method of securing suitable magnetic "fringe" with fair magnetic rigidity of field.



FIGS. 506 to 508.—Illustrating the alteration of magnetic field due to movement of mass of iron in the armature. If the masses of iron in the armature be so disposed that as it rotates, the distribution of the lines of force in the narrow field between the armature and the pole piece is being continually altered, then, even though the total amount of magnetism of the field magnet remain unchanged, eddy currents will be set up in the pole piece and will heat it. This is shown in the above figures, which represent the effect of a projecting tooth, such as that of a Pacinotti ring, in changing the distribution of magnetism in the pole piece.

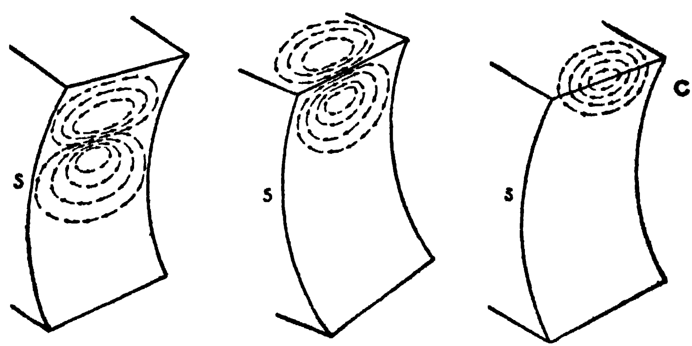


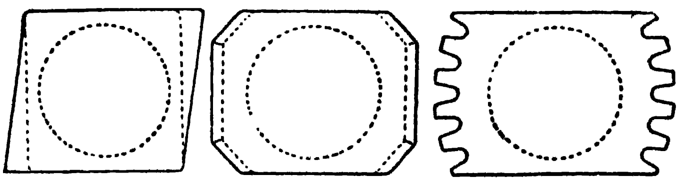
FIG. 509 to 511.—Eddy currents induced in pole pieces by movement of masses of iron. These diagrams, which correspond to those of figs. 506 to 508, show the eddy currents in pairs of vortices. The strongest current flows between the vortices and is situated just below the projecting tooth, where the magnetism is most intense; it moves onward following the tooth. At C, is shown what occurs during the final retreat of the tooth from the pole piece. These eddy currents penetrate into the interior of the iron, although to no great depth. Clearly the greatest amount of such eddy currents will be generated at that part of the pole piece where the magnetic perturbations are greatest and most sudden. A glance at the figures shows that this should be at the forward horn of the pole piece. However, when a dynamo, with horned pole pieces, has been running for some time as a motor the forward horns are cool and the hindward horns hot.

subject to *eddy currents*, that is, induced electric currents occurring where a solid metallic mass is rotated in a magnetic field. These currents consume a large amount of energy and often occasion harmful rise in temperature.

This loss may be almost entirely avoided by laminating the pole piece, or both pole piece and core; in the latter case, both form one part without any joint.

Ques. What is a laminated pole?

Ans. One built up of layers of iron sheets, stamped from sheet metal and insulated, as shown in fig. 531.



FIGS. 512 to 514.—Various shapes of pole piece for securing a gradual entrance of the armature inductors into the magnetic field.

Ques. What mode of construction can be used to reduce the reluctance of the magnetic circuit when laminated poles are used?

Ans. The reluctance can be reduced by cast welding the poles into the panel.

The frame end of the core when designed for cast welding has irregularities in the heights of the different sheets, as well as grooved undercut surfaces, in order to enable the molten metal of the frame to key well into the laminations of the core, making a good joint, both mechanically and electrically. By this construction, the continuity of the magnetic circuit is practically unbroken save for the air gap between the pole piece and armature.

Ques. What may be said of this construction?

Ans. Although an efficient method, the prevailing practice is to bolt the poles to the frame.

Fig. 531 shows a combined core and pole piece made entirely of sheet iron punchings assembled and riveted together. In some cases there is a longitudinal slot extending from the end into the core. This was first suggested by Lundell, the object being to prevent, as far as possible, the distortion of the magnetic field due to armature reaction especially on heavy overloads

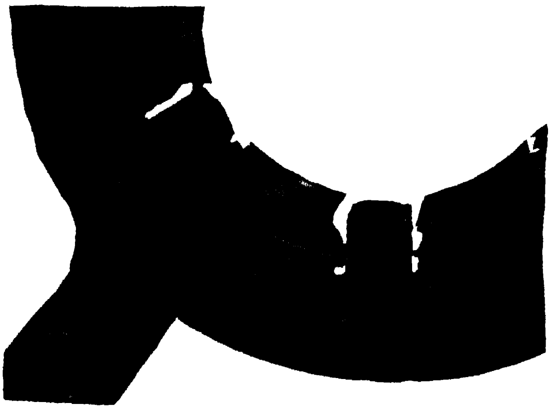


FIG. 515.—Ideal dynamo, detail of field showing main, and interpole field magnets.

NOTE.—*Characteristics of field coils.*—The shunt field coil is placed directly across the line, and as it has a constant resistance, the amperes flowing, and therefore its ampere turns, are dependent solely upon the voltage between its terminals, which voltage is very little changed by the load placed on the machine. Therefore, shunt field coils are constant in their strength with variable loads. Rheostats are placed in series with shunt field coils, in order to weaken or strengthen the field strength, and thereby change the performance of the machine. Series field coils are placed in series with the main armature leads of the machine, and as the current in the armature lead varies according to load required of the machine, the strength of this type of field coil varies directly with the load. For this reason, series field coils are used for street car motors and hoist motors, which require a very heavy torque, and therefore heavy fields when the loads are heavy. Motors with series fields must always be direct connected to a load, as under very light loads they would have a very light field, which would cause them to run away. Motors and dynamos both are built with a combination of shunt field coils and series field coils, and are then termed "compound wound machines." Motors built this way will have a higher starting torque and dynamos built with compound fields may have a constant or changed voltage characteristic, according to change of load.

Ques. What is the disadvantage of laminating a core?

Ans. It necessitates a nearly square or rectangular section which requires more copper for the winding than the cylindrical form.

The Magnetizing Coils.—The object of the magnetizing coils, is to *provide, under the various conditions of operation, the number of ampere turns of excitation required to give the proper flux through the armature to produce the desired pressure.*

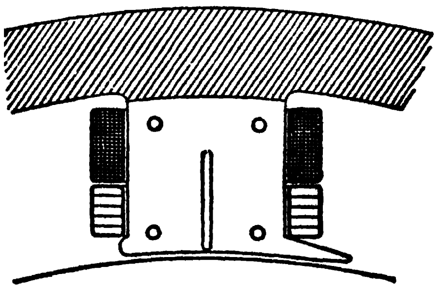


FIG. 516.—Lundell type of combined core and pole piece; a combination of Gravier's unsymmetrical horns and longitudinal slot designed to prevent distortion of field.

With respect to the manner in which magnetizing coils are wound they are said to be:

1. Spool wound;
2. Former wound.

Ques. Describe the methods of constructing spool wound coils.

Ans. The spool is made in various ways, sometimes entirely of brass, or of sheet iron with brass flanges, or of very thin cast iron. Some builders use sheet metal with a flange of hard-wood, such as teak.

If a spool be simply put upon a lathe to be wound, the inner end of the wire, which must be properly secured, should be brought out in such a way that it cannot possibly make a short circuit with any of the wires in the upper layers. To avoid this difficulty, the wire is sometimes wound on the spool in two separate halves, the two inner ends of which are united, so that both the working ends of the coil come to the outside as shown in fig. 517.

Ques. Describe the construction of former wound coils.

Ans. Former wound coils are wound upon a block of wood having temporary flanges to hold the wire together during the

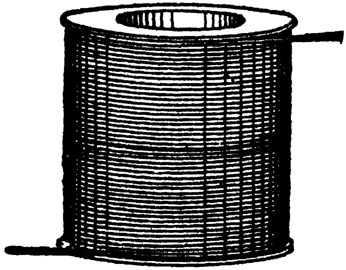
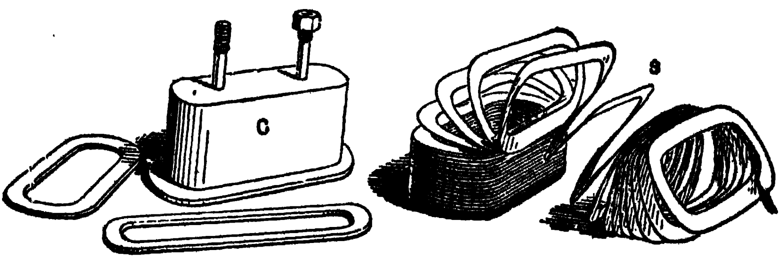


FIG. 517.—Method of winding magnet spool so that the two ends of the coil will come to the outside. This method has also been used for induction coils, where it is desirable to keep the ends of the wire away from the core and primary coil.



FIGS. 518 to 521.—Core and edge strip winding for shunt field coils of large multipolar dynamo. The winding consists of a copper strap S, carefully insulated and placed edgewise on the core C, in a single layer of winding. With this arrangement, the space occupied by insulation is reduced to a minimum, and, although the cooling surface is small, each turn of the winding has one edge on the outer surface, being ample for adequate cooling.

winding. Such coils have pieces of strong tape inserted between the layers and lapped at intervals over the windings to bind them together. Coils are usually soaked with insulating varnish and stove dried.

Ques. What may be said with respect to the coil ends?

Ans. Several methods of bringing out the ends of coils are shown in figs. 517 to 523. In figs. 518 to 521 copper strip,

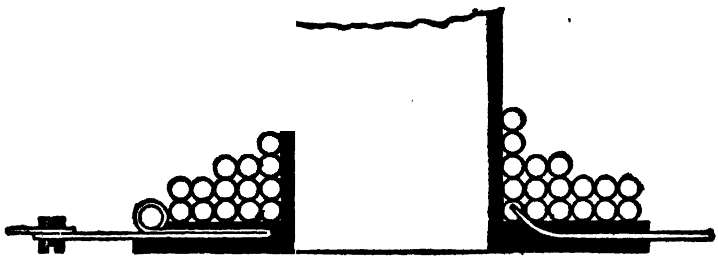


FIG. 522.—One mode of bringing out the coil ends, in which copper strip is laid in behind an end sheet of insulating material.

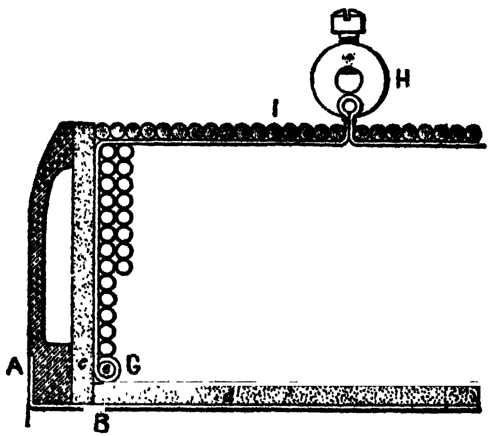


FIG. 523.—Another mode of bringing out the coil ends. A narrow insulated strip of thin paper G, leading to terminal H, is connected with the end e, of the coil before winding.

laid in behind an end sheet of insulating material, makes connection to the inner end, while another strip, similarly

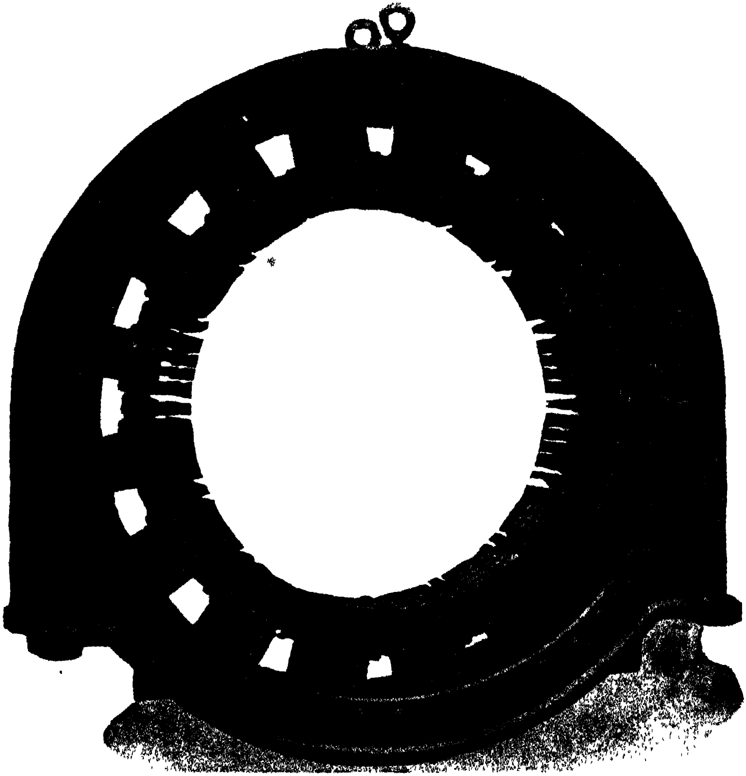


FIG. 524.—Ridgway 400 *k.w.* field ready to wind. ***In construction***, the field ring proper is constructed of laminated steel, the punchings being securely held between heavy cast iron clamping rings having a modified I beam section. The pole pieces are also laminated and are built in two separate parts. One part forms the core for the field coil while the other is the pole face, or, as it is sometimes termed, the pole shoe. The two parts are firmly bolted to the field ring by heavy cap bolts which pass through the field core and screw into the pole face. Between the pole faces are placed commutating or inter poles. These poles are built of laminated steel in the same manner as the pole pieces. The commutating poles are supported from the pole pieces by brass keys driven into slots in the sides of the commutating poles and the adjacent pole pieces. The pole pieces are provided with three slots, through which are wound the "compensating coils."

inlaid, serves as a mechanical and electrical attachment for the cuter end of the winding.

Two other methods are shown in figs. 522 and 523. A simple device for securing the outer end is to fashion a terminal piece so that it can be

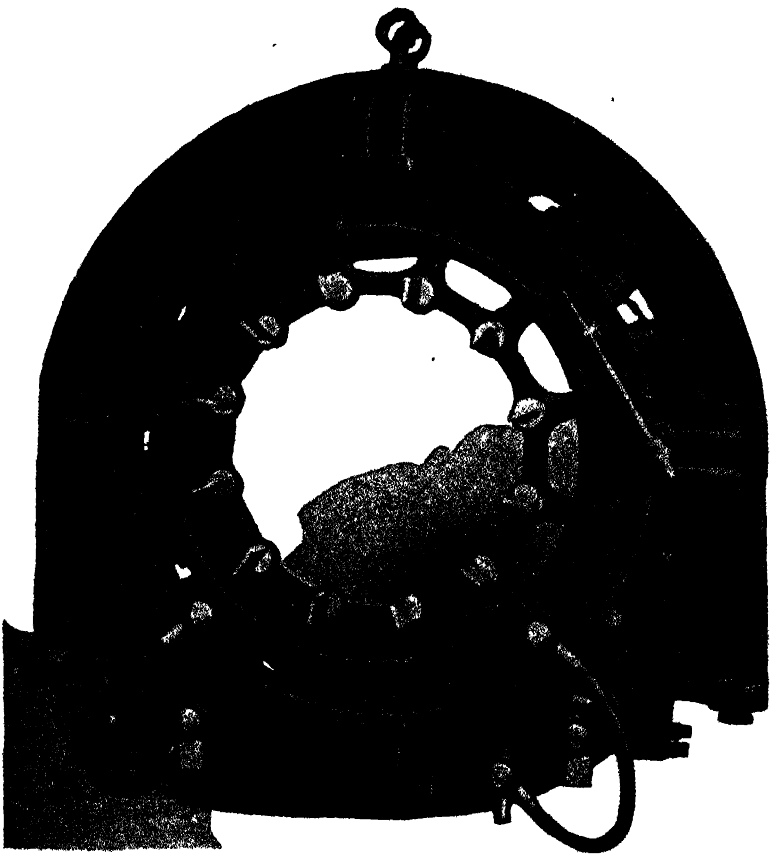


FIG. 525.—Ridgway 200 *k.w.* field complete; front view.

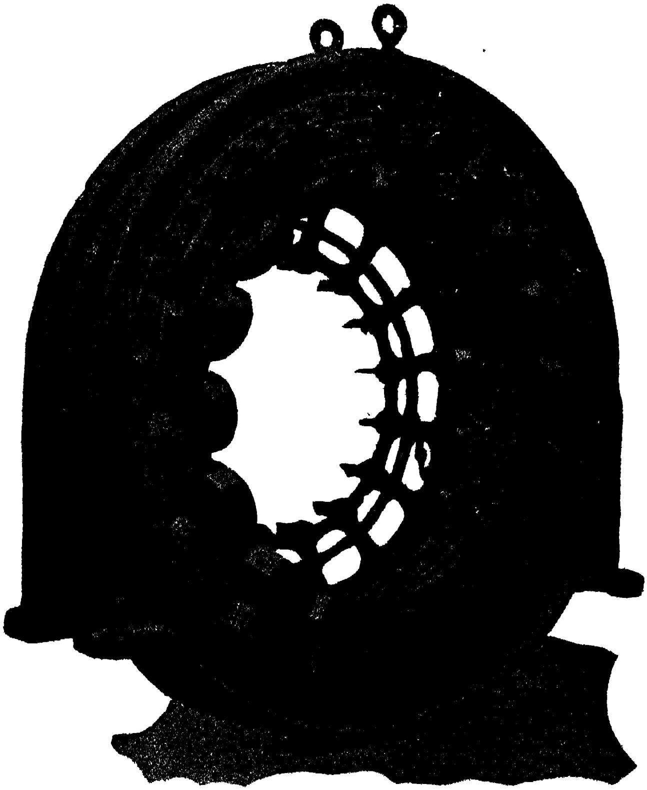


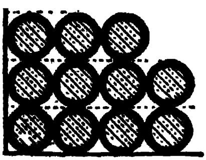
FIG. 526.—Ridgway 250 *k.w.* field complete; rear view. ***In construction,*** the shunt field coils are wound on forms, and after removal they are taped and dipped in insulating varnish. After baking, they are wound with heavy cotton cord and again varnished. Numerous fiber buttons project from the surface of the coil and add to its ventilation and insulation. Any coil may be removed without disturbing any other coil or part. This is done by taking out the two cap bolts which hold the pole piece in place, and driving out one of the brass keys holding the commutating pole. The coil and its core may then be taken out at either side of the field. The compensating coils correspond to the series coils of the ordinary compound wound dynamo. These coils lie parallel to the armature bars, but they are so wound that the current in them flows in the opposite direction to that in the armature bars. Being in series, the current in the compensating coils and armature is the same. Due to the current flowing in them, the balancing coils set up a local magnetic field which is opposite in direction to that set up by the armature bars. These two fields neutralize or balance each other, and the distorting effect of the armature current is reduced to zero. The result of this is to hold

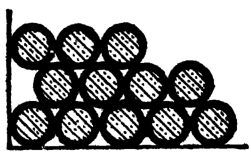
laid upon the winding, the last three or four turns of which are wound over its base, and after winding, are bared at the place and securely soldered.

Ques. How are the coils insulated?

Ans. The spools upon which the coils are wound are usually insulated with several layers of paper preparations; a thickness of one-tenth of an inch made up of several superposed layers is generally sufficient.

Varnished canvas is useful as an underlay, and vulcanized fibre for lining the flanges. It is important to protect the joint between the cylindrical part and the flanges. A core paper may be laid upon every four layers of winding. Between series and shunt coils, in compound wound machines there should be an insulation as efficient as that on the cores.





FIGS. 527 and 528.—Square and hexagonal order of "bedding." The term bedding is an expression used to indicate the relation between the cross sectional area of the winding when wound square, as in fig. 527, and where wound in some other way, as in fig. 528. In the square order of bedding, the degree of bedding equals zero.

FIG. 526.—*Text continued.*

stationary the field due to the shunt coils, and give a fixed plane of commutation. As the load increases, the neutralizing effect of the compensating coils increases proportionately and the commutation plane remains as before. The central portion of each compensating coil is wound around the commutating pole and sets up a secondary field between the pole faces. It is in this field that the short circuiting of each armature coil takes place as it passes from a positive to a negative pole, or vice versa. This field being the result of the current output of the dynamo is likewise proportional to the load. This is the correct condition for sparkless commutation.

NOTE.—A third function of compensating coils is to build up the field as the load increases, in order to obtain a compounding effect. This is secured by winding the coils eccentrically and by adding a few extra turns. Likewise, the design of the magnetic circuits has an influence on the result. The degree of compounding may be varied somewhat by simply shifting the brushes. To sum up, the compensating coils serve the following purposes; they neutralize armature reaction, giving fixed brushes; they provide a commutating field proportional to the load, giving sparkless commutation, with its resulting low commutator temperature, and heavy overload capacity; and lastly, they provide a degree of compounding which is entirely in the hands of the designer.

When the winding is completed, two layers of pressed board or equivalent are laid over and bound with an external winding of hard rope or tape. This protective external lagging covering the outer surface of the completed coils is not altogether a benefit for it tends to prevent dissipation of heat.

Ques. How are the coils attached?

Ans. Where the pole pieces are simply extensions of the cores without enlargement, the coils can be slipped over the

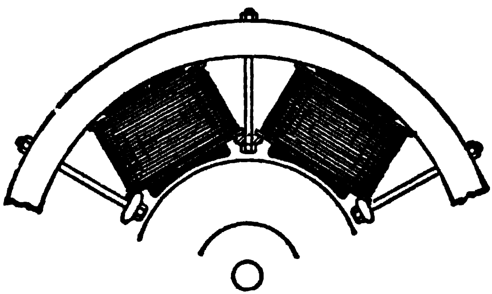


FIG. 529.—Method of securing coils in position when the pole pieces are simply extensions of the core without enlargement.

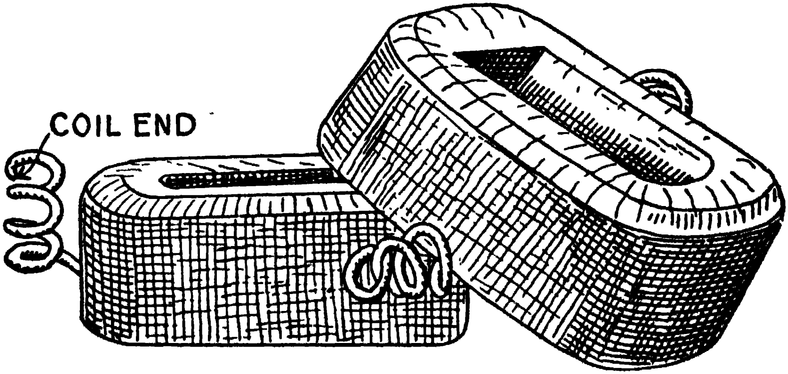


FIG. 530.—Western Electric set of former wound field coils for four pole dynamo. These coils are wound around a former or template, and are then slipped over the cores before the latter are bolted to the yokes or frame.

ends, but some kind of clamping device is necessary to hold them in place, as for instance, the method shown in fig. 529.

In case the pole piece be made larger than the core and separate therefrom, it is put into position after the coils are in place, thus serving the double purpose of pole piece and clamp.

Ques. Describe the coil connections.

Ans. Coils are generally united in series so that the same

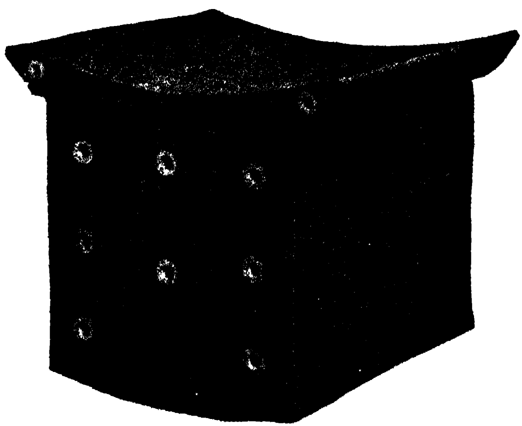


FIG. 531.—General Electric main pole piece of bolted construction.

magnetizing current may flow through all of them. The coils should be so connected that they produce alternate north and south poles.

If all the coils be similarly wound with respect to the terminals, and similarly placed; that is, so placed that the winding, considered from the coil terminal nearest the pole face, starts in all the coils in the same direction, then the connections will come at the north end and at the south end of the spools.

Heating.—The heat generated in the magnetizing coils is dissipated in three ways; by:

1. Conduction;
2. Radiation;
3. Convection.

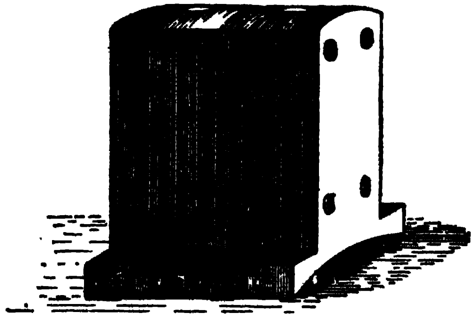


FIG. 532.—Rectangular type laminated magnet core for dynamo. The laminations are of soft mica or steel sheets to reduce hysteresis and eddy current losses.

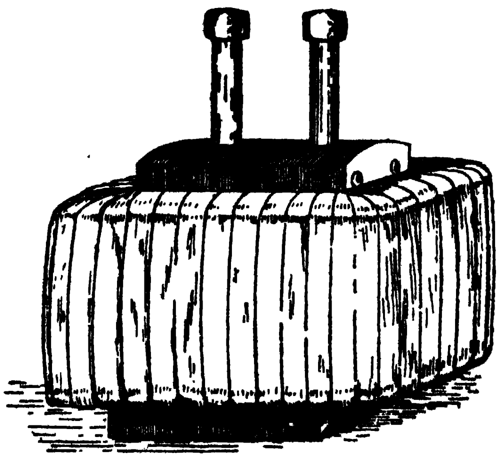


FIG. 533—Assembly of laminated magnet core and coil.

In the first instance, it passes through the copper and the insulation, either to the external surface, whence it passes off by radiation and convection into the air, or to the magnet core and yoke, which in turn conduct it away. In large multipolar machines the masses of metal in the pole cores and frame are more efficient in dissipating heat than the external surface of the coil.

FIG. 534.—Compound wound rectangular ventilated spool field coil. The series and shunt coils are wound side by side, ventilating passages being provided lengthwise through each coil and between the shunt and series coils as shown.

Ventilation.—Sometimes provision is made for ventilation of the field magnet coils as shown in fig. 534. Here the series and shunt coils are wound side by side, ample ventilation being provided lengthwise through and between the coils.

TEST QUESTIONS

1. *What is the object of the field magnets?*
2. *Why are electro field magnets used in place of permanent field magnets?*
3. *What are the four essential parts of a field magnet?*
4. *What is the object of the yoke and how is it constructed?*
5. *What is carried by the cores?*
6. *Name two general classes of field magnets, and give distinction.*
7. *What result is obtained by the use of multipolar field magnets?*
8. *How are multipolar field magnets arranged around the armature?*
9. *What materials are used for field magnets and what governs the choice of materials?*
10. *What is the object of dividing a yoke and the objection?*
11. *How is the reluctance of the yoke joint reduced?*
12. *Why are pole faces made larger than the coils?*
13. *What are eddy currents and how are they overcome?*
14. *How are the magnet coils wound, attached, and connected?*
15. *How is heat in magnet coils dissipated?*
16. *How is ventilation secured?*

CHAPTER 18

The Armature

The armature of a dynamo *consists of coils of insulated wire wound around an iron core, and so arranged that electric currents are induced in the wire when the armature is rotated in a*

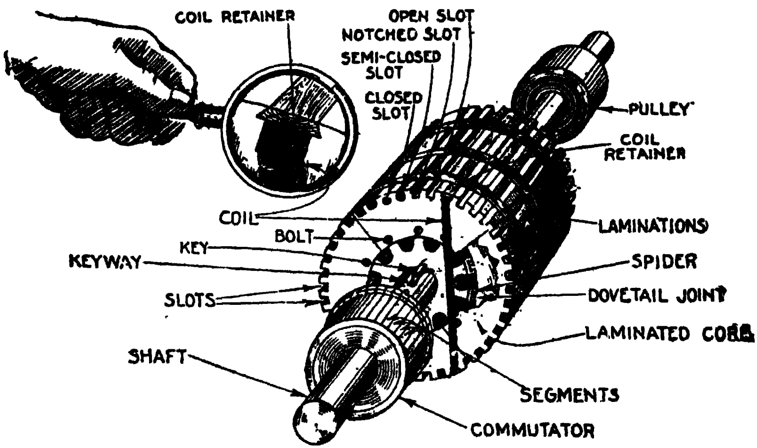


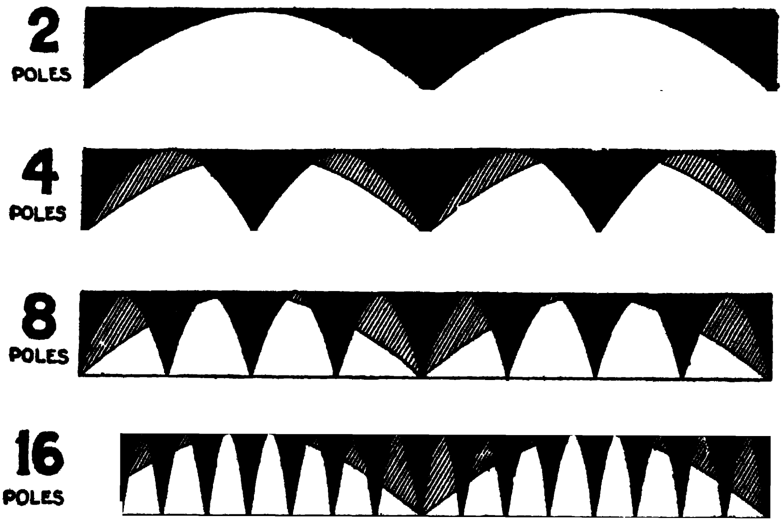
FIG. 535.—Armature with names of parts.

magnetic field or the field magnets rotated and armature held stationary.

The commutator is in fact a part of the armature, but is of sufficient importance to be considered in a separate chapter.

Ques. What are the practical objections to the elementary armature, described in fig. 427?

Ans. It induces a very feeble current, which is not of constant pressure, but pulsating; that is, it consists of two pronounced impulses in each revolution as shown in fig. 428.



FIGS. 536 to 539.—Sine curves illustrating effect of increasing number of poles. The two pole curve is reproduced in each diagram for comparison.

Ques. Why does the elementary armature produce a pulsating current?

Ans. The pulsations are due to the coil moving alternately into, and out of, the positions of best and least action in the magnetic field.

Ques. How is a continuous current, or one of uniform pressure obtained?

Ans. If two additional coils be added to the elementary armature, at right angles to the existing coils, and the ends suitably connected to a four part commutator, as in fig. 429, so that one pair is in the position of best action, while the other is in the position of least action, the pulsations of the resulting current will be of less magnitude. By increasing the coils and suitably altering the construction of the commutator to

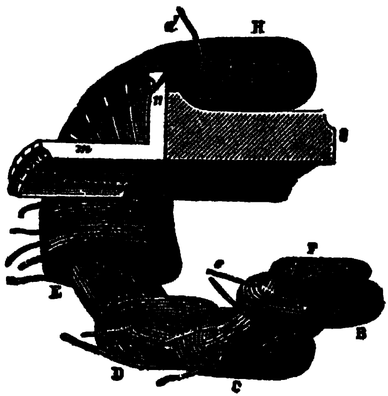


FIG. 540.—Early form of Gramme ring armature, the core being shown cut through, and some of the coils displaced to make it clearer. The core, F, consists of a quantity of iron wire wound continuously to form a ring of the shape shown by the section. Over this is wound about thirty coils of insulated copper wire, BCD, etc., the direction of the winding of each being the same, and their adjacent ends connected together. The segments consist of corresponding number of brass angle pieces, *m*, *n*, which are fixed to the wooden boss *o*, carried on the driving shaft. The junction of every two adjacent coils is connected to one of the commutator segments, as shown at *n*.

accommodate the ends of these coils, the resultant current may be represented by practically a straight line, indicating the so called *continuous current*, instead of the wavy resultant curve No. 6, as illustrated in fig. 433.

An armature for practical use has a large number of coils, suitably arranged upon an iron core, so that a large proportion of them are always

actively cutting the lines of force, or moving into the positions of best action in the magnetic field.

Types of Armature.—Although there are many forms of armature, all may be divided into three classes, according to the arrangement of the coils or winding on the core, as:

1. Ring armatures;
2. Drum armatures;
3. Disc armatures.

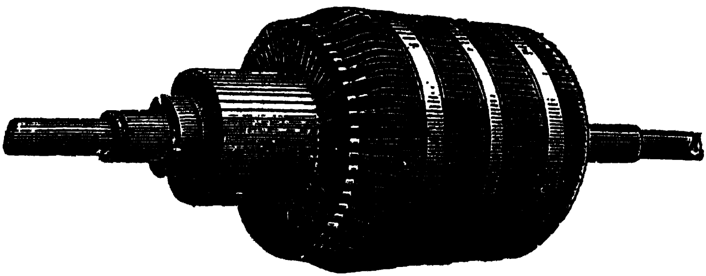


FIG. 541.—Later form of Gramme ring armature. *The core consists of* a number of thin flat rings of well annealed charcoal iron, the outer diameter of each ring or disc being 11⅛ inches, and its inner diameter 9¼ inches. Sheets of thin paper insulate each disc from its neighbors to prevent the flow of eddy currents. The armature is mounted on a steel shaft to which is keyed a four armed metal "spider," the extremities of whose arms fit into notches cut in the inner edges of the soft iron core rings, so that a good mechanical connection is obtained between the core and the shaft. The spider is made of a non-magnetic metal, to reduce the tendency to leakage of lines of force across the interior of the armature. The armature inductors consist of cotton covered copper wire of No. 9 standard wire gauge, wound around the core in one layer, and offering a resistance, from brush to brush, of .048 ohm. There are two convolutions in each section, the adjacent ends of neighboring sections being soldered to radial lugs projecting from the commutator bars.

Each of these forms of armature has its own special advantages for particular purposes, the disc type being least in favor and not having had any extensive application in this country being now obsolete.

At present practically the only type of armature in commercial use is the drum type; however, the actions within the core and winding of an armature can be illustrated best by diagrams

of the ring type, which accordingly are sometimes used in explaining principles. The same principles apply equally well to drum armatures.

Ques. What is the comparison between ring and drum armatures?

Ans. The drum armature is electrically and mechanically the more efficient, possessing, as it does, possibilities in the way of better mechanical construction of the core, and in the arrangement and fixing of the inductors thereon not to be

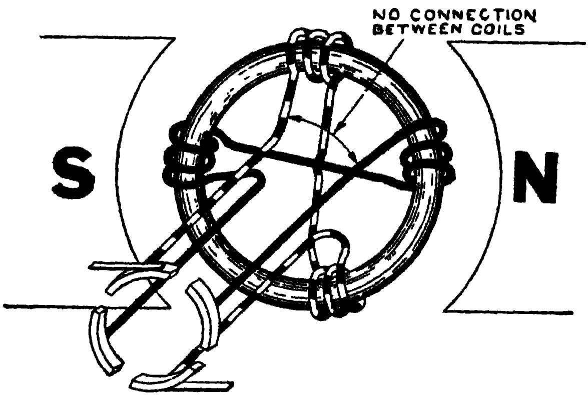


FIG. 542.—Open coil ring armature in which separate coils or sections of the winding are not united in one closed circuit. Formerly when series arc lighting was the prevailing method of street illumination open coils were used as the air insulated commutators employed with the coils were well adapted to collecting current at the high pressure necessary for the arc system.

found in the ring form. Less wire and magnetizing current are required for the field magnets for a given output than with the ring armature. Drum winding is not so simple as ring winding, and it is more difficult to ventilate a drum than a ring armature, it being necessary to provide special ventilating ducts.

Ques. Describe a ring armature.

Ans. It consists essentially of an iron ring, around which

is wound a number of coils. These various coils are wound on separately, the wire being carried over the outside of the ring, then through the center opening and again around the outside, this operation being repeated until the winding for that individual section is completed. The adjacent coil is then wound

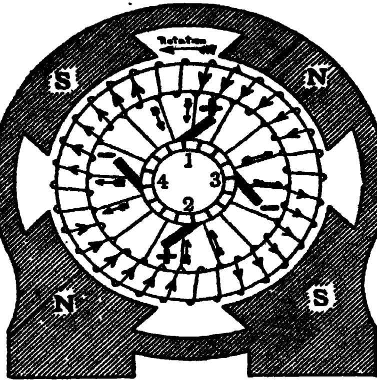


FIG. 543.—Ring armature of four pole dynamo; diagram of winding and connection showing direction of the induced currents. *The currents* in the windings under the upper *N* and *S*, poles are opposed to each other and flow to the external circuit by the positive brush 1, and back to this half of the armature by the negative brushes 3 and 4. At the same instant the opposed currents in the lower windings flow to the external circuit by positive brush 2, and return to the armature through negative brushes 3 and 4. The armature is thus divided into four circuits and four brushes are required which must be placed between the poles so as to short circuit the coils as they pass through the neutral space. In this form of winding there is no difference of pressure between the + brushes, so that they are connected in parallel, as are also the negative brushes, and then to the external circuit. In multipolar machines there are as many brushes as pole pieces. Since opposite commutator bars are of the same pressure on this four pole dynamo they may be joined by a cross connecting wire and two brushes, as 2 and 4, dispensed with. This can only be done when there is an even number of coils. The armature is said to be "cross connected."

in the same way, the ends of each being brought out to the commutator side of the armature, the arrangement of the coils on the ring and connections with the commutator being shown in fig. 542, examples of actual construction being shown in figs. 540 and 541.

Ques. For what conditions of operation is the ring armature specially adapted, and why?

Ans. It is well suited to the generation of small currents at high voltage, as for series arc lighting, because the numerous coils can be very well insulated.

Ques. Why does a ring armature require more copper in the winding than a drum armature?

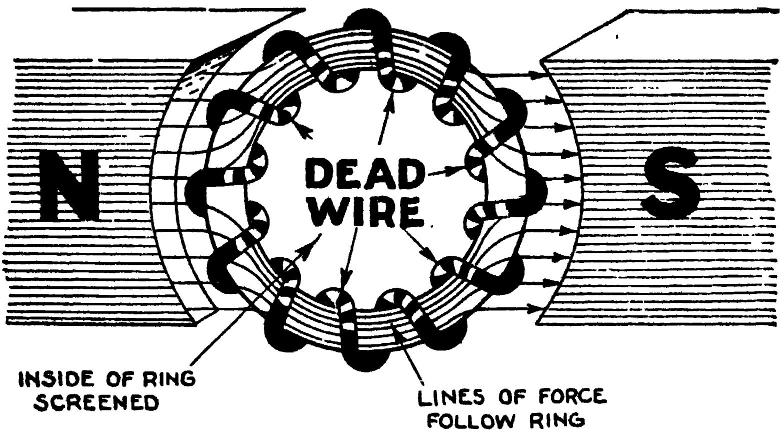


FIG. 544.—Distribution of magnetic lines of force through a Gramme ring. Since the metal of the ring furnishes a path of least reluctance, most of the magnetic lines will follow the metal of the ring and very few will penetrate into the aperture of the interior. This condition causes a serious defect in the action of ring armatures, rendering the winding around the interior useless for the production of electric pressure. Hence, in ring armatures only about half of the winding is effective, the rest or "dead wire," adding its resistance to the circuit, thus decreasing the efficiency of the machine.

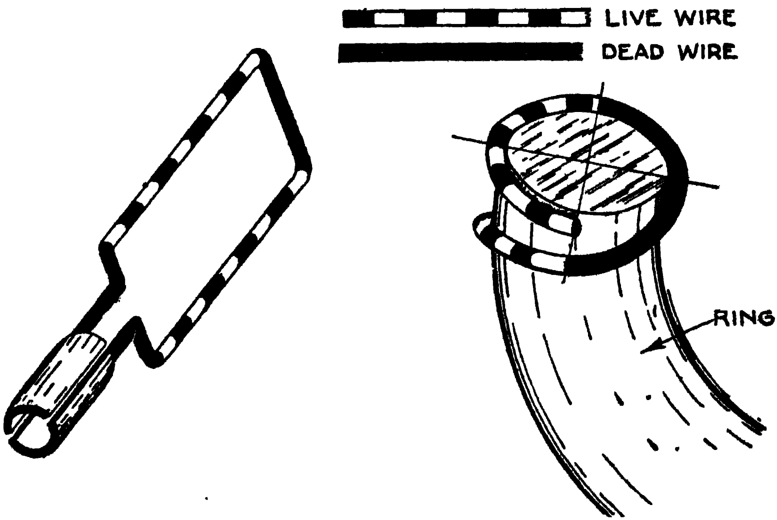
Ans. For the reason that those inductors which lie on the inner side of the iron ring, being screened from practically all the lines of force, as shown in figs. 544 and 548, do not generate any current.

Numerous attempts have been made to utilize this part of the winding

by making the pole pieces extend around the ring in such a manner that lines of force will pass to the inside of the ring, also by arranging an additional pole piece on the inside of the armature, but mechanical considerations have shown these methods to be impractical.

Ques. Is any portion ot the winding of a drum armature inactive?

Ans. Yes; the end connectors do not generate any current.



FIGS. 545 and 548.—Comparison of ring and drum armatures showing relative amount of dead wire, that is, portions of the windings in which induction does not take place.

Ques. What is the chief advantage of the drum armature?

Ans. It reduces considerably the large amount of dead wire necessary with the ring type.

Ques. How is this accomplished?

Ans. By winding the wire entirely on the outer surface of a cylinder or *drum*, as it is called, none of the wire is screened by the metal of the core. Fig. 547 indicates this; compare with fig. 548.

Fig. 550 shows an elementary four coil drum armature. Starting from the point *a* and following the winding around without reference at first to the commutator, it will be found that the rectangular turns of the wire form a closed circuit, and are electrically in series with one another in the order of the numbers marked on them.

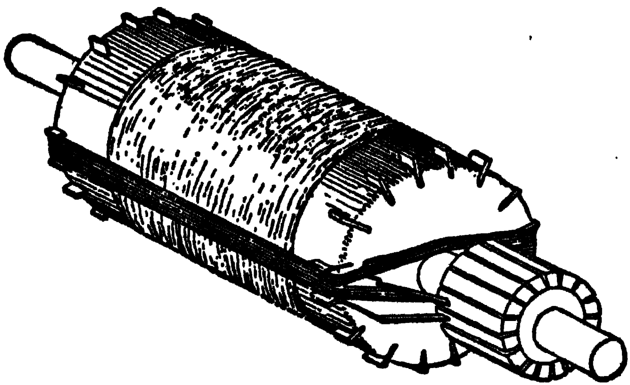


FIG. 549.—Illustrating the principle of diametrical or Siemens' drum winding. In order to make the winding and connections clear, one coil and the commutator is shown assembled, although the latter is not put in place until after all the sections have been wound, the ends of the wires being temporarily twisted together until all can be soldered to the risers. The cores of these early machines were of wood overspun circumferentially with iron wire before receiving the longitudinal copper windings.

NOTE.—*Siemens, Ernest Werner Von.*—Born 1816, died 1892. A German electrical _, brother of Sir William Siemens. He early applied himself to the study of chemistry and electromagnetism, inventing a process of electroplating in 1841. In 1848 he exploded a submarine mine for the first time by means of an electric current. The following year he began to devote himself to establishing telegraph systems in various parts of Europe. He invented an improved form of shuttle armature in 1856, which was known as the Siemens armature, and was the promoter of electric traction in Germany (1879) establishing the famous engineering firm of Siemens & Halske. His experiments resulted in the discovery of many facts of great value in electrical practice, and the development of important apparatus. In 1884 he contributed a large sum of money to establish the Imperial Physico-Technical Institute which has been a great factor in German engineering progress.

With respect to the connections to the four segments *w,x,y,z*, of the commutator it will be found that at two of these, *x* and *y*, the pressures in the windings are both directed *from*, or both directed *toward* the junction with the connecting wire. At the other two segments, *z* and *w*, one pressure is toward the junction and the other directed from it. If, therefore, the brushes be placed on *x* and *y*, they will supply current to an external circuit *z* and *w*, for the moment being idle segments.

Disc Armatures.—The inductors of a disc armature ***move in a plane, perpendicular to the direction of the lines of force, about an axis parallel to them*** as shown in fig. 551.

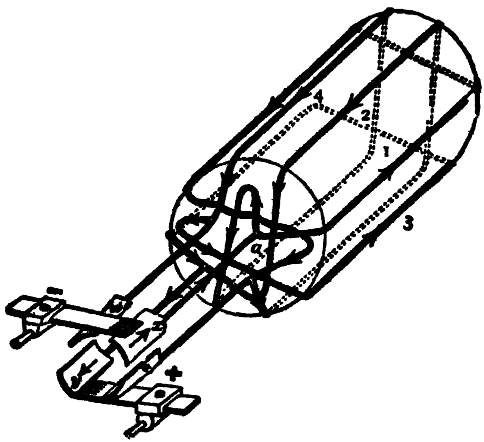


Fig. 550.—Elementary four coil drum winding, showing the connections with the segments, and direction of currents in the several coils. The action of this type of armature is fully explained in the text.

The main difficulty with this type has been in constructing it so that it will be strong and capable of resisting wear and tear. It was introduced in an effort to avoid the losses due to eddy currents and hysteresis present in the other types of armature.

On account of the nature of the construction of a disc armature, it is

necessary that the coils subject to induction occupy as small a space as possible in the direction of their axes. This requirement, as well as the connection of the inductors with each other and with the commutator, prevented the general adoption of this form of armature, and subsequent experience failed to justify the existence of the type.

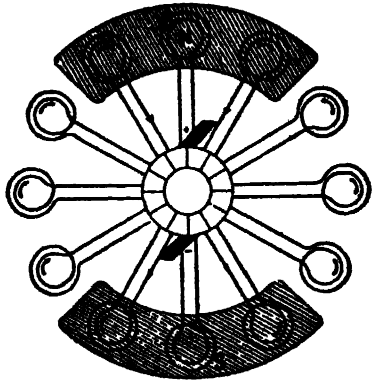


FIG. 551.—Disc armature of Niaudet. It is equivalent to a ring armature, having the coils turned through an angle of 90°, so that all the coils lie in a plane perpendicular to the axis of rotation. The connections of the coils with each other and with the commutator remain the same, the beginning and the end of adjacent coils leading to a common commutator bar as shown. The magnetic field is arranged by the use of two magnets, so arranged as to present the north pole of one to the south pole of the other, and *vice versa*. In the figure one of these magnets is considered as above the paper, and the other below. If this armature be rotated through the magnetic field as shown, a reversal of current takes place in each coil, when it is in such a position that one of its diameters conicides with the pole line *NS*. If the brushes be set so as to short circuit the coils that are in this position, the armature will be divided into two branchings, the current flowing in an opposite direction in each, and a direct current will flow in the exterior circuit.

TEST QUESTIONS

1. *What is the construction of the armature of a dynamo?*
2. *What are the practical objections to armatures with but few coils?*

3. *Why is a pulsating current produced in an elementary armature?*
4. *How is a current of uniform pressure obtained?*
5. *Name three general classes of armatures.*
6. *What is the prevailing type of armature?*
7. *Compare ring and drum armatures.*
8. *Describe in detail ring and drum armatures.*
9. *For what service are ring armatures adapted, and why?*
10. *What is the chief defect of a ring armature?*
11. *How is the amount of dead wire reduced in drum armatures?*
12. *Describe the operation of a disc armature.*
13. *What is the main difficulty of the disc type, and why was this type introduced?*

CHAPTER 19

Armature Windings

To connect up rightly the inductors on an armature so as to produce a desired result is a simple matter in the case of ring winding, for bipolar or multipolar machines. It is a less easy matter in the case of drum winding, especially for multipolar machines.

Often there are several different ways of arriving at the same result, and the fact that methods which are electrically equivalent may be geometrically and mechanically different makes it desirable to have a systematic method of treating the subject.

The elementary arrangement of drum and disc armatures has already been considered, which is sufficient explanation for small armature coils of only a few turns of wire, but in the case of larger machines which require many coils, further treatment of the subject is necessary.

For example, in order to direct the winder how to make the connections for, say a four pole machine having 100 bars spaced around its armature, some plain method of representing all the connections so that they may be easily understood is necessary. From this the workman finds out whether he is to connect the *front** end of bar No. 1 across to 50 or across a quarter of the circumference to 25, or across three quarters of it to bar 75. Again, he ascertains to which bar he is to connect the *back** end of the bar, and how the bars are to be connected to the commutator.

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*NOTE.—The "front" end means the end at which the commutator is located. Armatures are most conveniently regarded from this end, the opposite end being known as the "back" end

Winding Diagrams and Winding Tables.—In the construction of armatures, instructions to winders are given in the form of diagrams and tables. In the tables the letters F and B stand for *front* and *back*, meaning *toward* the front end, and *from* the front end respectively. The letters U and D stand for *up* and *down*.

There are three kinds of winding diagram:

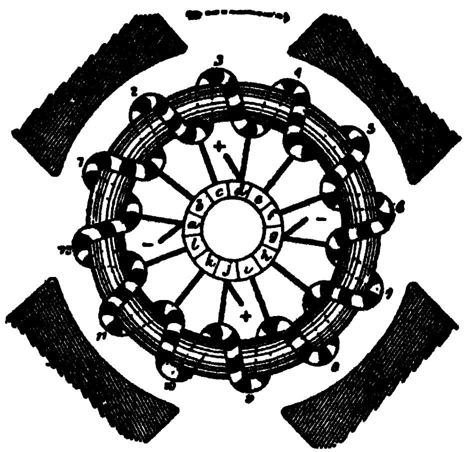
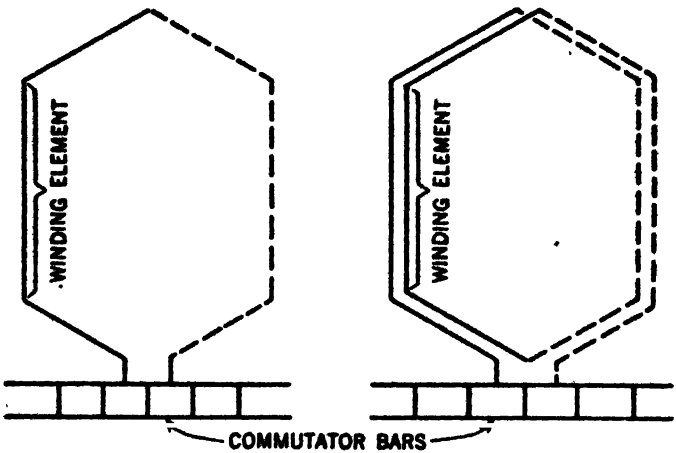


FIG. 552.—End view of ring winding for a four pole machine. *An end view* is simply a view showing the arrangement of the armature inductors and connections *looking from the front of commutator end.*

1. End view diagram;
2. Radial diagram;
3. Developed diagram.

The end view is simply a view showing the arrangement of the armature inductors and connections looking from the front or commutator end, such as shown in fig. 552.

Coil Element.—The group of wires, figs. 5 and 6, constituting the side of a coil and usually wrapped together with tape as a unit, is termed a *winding element*. Since each coil has two sides, there will always be twice as many coil elements as there are coils in a winding.



FIGS. 5 and 6.—Showing single coil representing a two-turn coil of an armature winding.

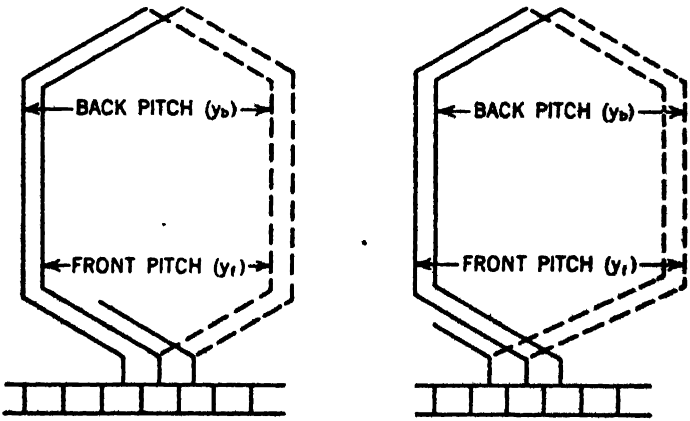
Coil Pitch.—The number of slots spanned by one coil is termed the *coil* or *winding pitch*. When a coil spans exactly the distance between the center of the adjacent field poles, it is said to have a *full pitch* coil.

Fractional Pitch Coils.—In case the coil spans less than full pitch, it is said to have a *fractional pitch* and such a winding is often termed a *short cord winding*.

These are frequently used because they have shorter end connections, thus requiring less copper and are easier to install in the slots. In addition armature reaction is reduced since the currents in the neutral zone flow partly in opposite directions and neutralize each other.

Front Pitch.—The distance between two sides of a coil connected to the same commutator segment, measured in coil sides at the front or commutator end of the armature is termed the *front pitch.*

Back Pitch.—Similarly the distance between the two sides of a coil measured in coil sides, at the back end of the armature, is termed the *back pitch.* The front pitch may be greater or less than the back pitch, but not equal to it.



FIGS. 7 and 8.—Illustrating a progressive and retrogressive lap winding, respectively.

Commutator Pitch.—Distance between the two commutator bars connected to the ends of a coil, measured in commutator bars.

Meaning of Terms *Progressive* and *Retrogressive*.—If the front pitch is less than the back pitch, the winding is termed *progressive*, that is, it advances in a clockwise direction when viewed from the commutator end. On the other hand, if the front pitch is greater than the back pitch, the winding is termed *retrogressive*, advancing in a counterclockwise direction.

Type of Winding Diagrams.—In the construction of armatures, instructions are usually given in forms of diagrams and tables. There are usually two types of winding diagrams, termed *radial* and *developed* view.

In the radial diagram the conductors of the armature are represented by short radial lines, while the end connectors are represented by curves or zig zags, those at one end of the armature being drawn within, those at the other end without the circumference of the armature. With the radial diagram it is easier to follow the circuits and to distinguish the back and front pitch of the winding.

The developed diagram is a mode of representation, in which the armature winding is considered as though the entire structure had been laid out on a flat surface.

Tracing a Simplex Lap Winding.—A typical diagram of a lap winding is shown in fig. 9. A tracing of the circuit shows that starting at the brush *B* and passing successively through the conductors *7*, *12*, *9* and *14*, the brush *C* is reached, and that the *e.m.f.*'s induced in each conductor is that in the direction of travel of the point which traces out this path. Again starting at brush *B* and passing successively through the conductors

10, *5*, *8* and *3*, the brush *A* is reached, the induced *e.m.f.*'s in these conductors likewise being in the direction of travel of the point which traces out this path.

It follows that the brush *B* is negative and that both brushes *A* and *C* are positive and at the same potential above brush *B*. Brushes *A* and *C* may, therefore, be connected together in parallel as indicated. Following through the two paths through the winding from brush *C* to brushes *B* and *D*, respectively, it will be observed that the brush *D* is at the same potential as brush *B*. Now since both brushes *B* and *D* are at the same negative potential, they may also be connected together in parallel as indicated.

This winding requires as many brushes as there are poles in the machine.

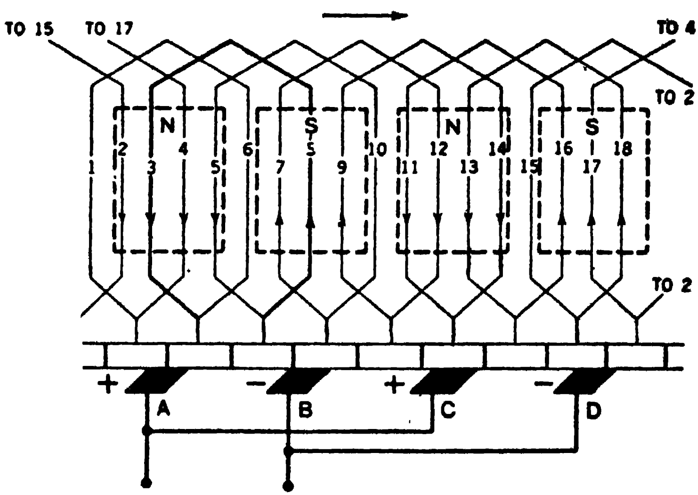


FIG. 9.—Simplex four pole lap winding.

Winding Tables.—As previously pointed out, armature winding instructions are usually computed in table forms, which are conveniently used not only for completion of the winding, but also for checking the finished winding. By inspection it may be determined whether or not each conductor is included once, and only once, and also whether the winding closes at the same conductor at which it began. With reference to fig. 9, starting at *1*, the table will progress as follows:

1-6-3-8-5-10-7-12-9-14-11-16-13-18-15-2-17-4-1.

Other winding diagrams may be put in table form in a similar manner.

Symbols Used in Lap Windings.—The difference in construction between a wave and lap winding pertains to the method of connecting together the individual coils, they being easily distinguished by an inspection of the end connections. Thus in the *wave winding* the end connections at the front and rear of the armature continue in the same direction around the armature as shown in fig. 11, while in the lap winding the front and rear connections lead in opposite directions as indicated in fig. 10.

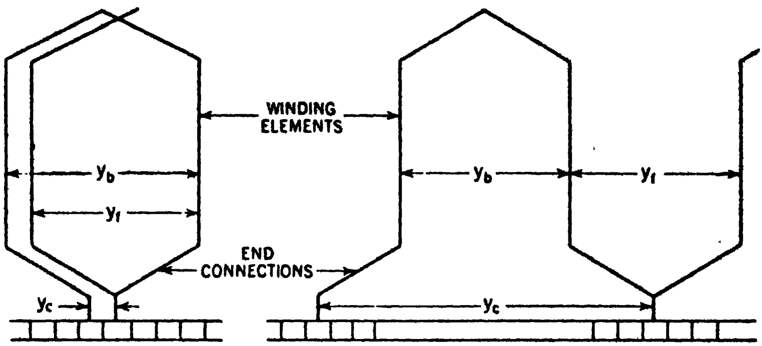
In determining the number of coils to be used in an armature winding there are certain rules that must be observed, which are briefly as follows:

1. The front and back pitch must both be odd numbers, and in the lap winding must differ by *two* or some multiple thereof.
2. In the wave winding the front and back pitch may be equal or may differ by *two* or some multiple thereof.
3. In the lap winding the front and back pitches are of opposite sign, that is, they are laid off in opposite

directions on the armature, while in the wave winding they are of the same sign.

4. The commutator pitch is equal to the average of the front and back pitches.

In applying these rules and the formulae which follow, it is necessary when slotted armatures are used to adhere to a definite method of numbering the elements of the windings.



FIGS. 10 and 11.—Illustrating a lap and wave winding, respectively, and symbols used in winding formulae.

If the winding element, figs. 10 and 11, lying in the top slots of fig. 12 are given odd numbers, it will readily be observed that since one side of a coil lies in the bottom of the slot, the other side of the same coil must lie in the top of some other slot. Thus with reference to figs. 10 and 11, y_b and y_f must both have odd numbers if the winding is to be placed properly on the armature.

It follows that the front and back pitches must differ from each other by 2. Thus for the lap winding in fig. 10 we obtain:

$$\text{back pitch} = y_b = \frac{s \pm b}{2p} \tag{1}$$

$$\text{front pitch} = y_f = y_b \pm 2 \tag{2}$$

$$\text{average pitch} = y \pm 1 \tag{3}$$

$$\text{commutator pitch} = y_c \pm 1 \tag{4}$$

Where s = number of half coils or elements in the winding.
p = number of pairs of poles in the machine.
b = a number which will make y_b and y_f odd integers (whole numbers).

For $b = 0$, the back pitch becomes equal to the whole pitch; if b is positive, y_b becomes greater than the pole pitch and the winding is termed progressive; if b is negative y_b becomes less than the pole pitch and the winding is termed retrogressive. As a rule b is negative and y_b becomes less than the pole pitch, that is, y_b is made equal or less than the pole pitch.

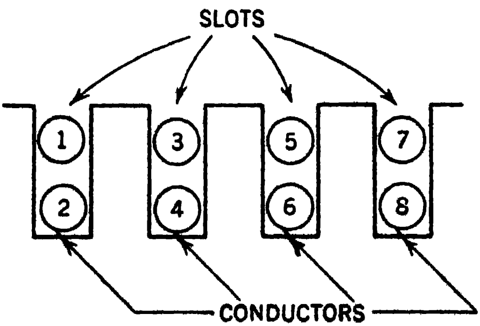


FIG. 12.—Showing method of designating numbers to coil elements.

The simplex lap winding has as many parallel circuits as there are poles in the machine. However, in cases where it is necessary to obtain a heavy current, duplex or triplex lap windings are sometimes used. The duplex lap winding is obtained by placing two similar windings on the same armature and connecting the even numbered commutator bars to one winding and the odd numbered ones to the second winding. Similarly, in the triplex lap winding, each section of the winding would connect to one-third of the commutator bars. For these windings:

$$y_b = \frac{s \pm b}{2p}, \text{ and} \tag{5}$$

$$y_f = \frac{s \pm b}{2p} \pm 2m; \tag{6}$$

$$y_c = \frac{y_b - y_f}{2} = \pm m \tag{7}$$

$$y = y_b - y_f = \pm 2m \tag{8}$$

Where m = an integer greater than one, that is, two for a double winding, three for a triple winding, etc., if the number of commutator bars is exactly divisible by m the several windings will be entirely separate from each other.

Multiplex Windings.—Multiplex windings are being used where the armature is required to carry a current which is higher than that allowed for the simplex lap type. Double layer windings of this type are shown in figs. 13 and 14.

The winding shown in fig. 13 has 16 coils in 16 slots. An inspection shows that $s = 32$, $b = 4$, and $p = 2$ (4 poles). With reference to equations (1) and (2) we obtain:

$$y_b = \frac{32 - 4}{4} = 7 \text{ and } y_f = \frac{32 - 4}{4} + 2 = 9.$$

In this winding the coil pitch y_b is equal to the pole pitch; therefore, it is a full pitch winding.

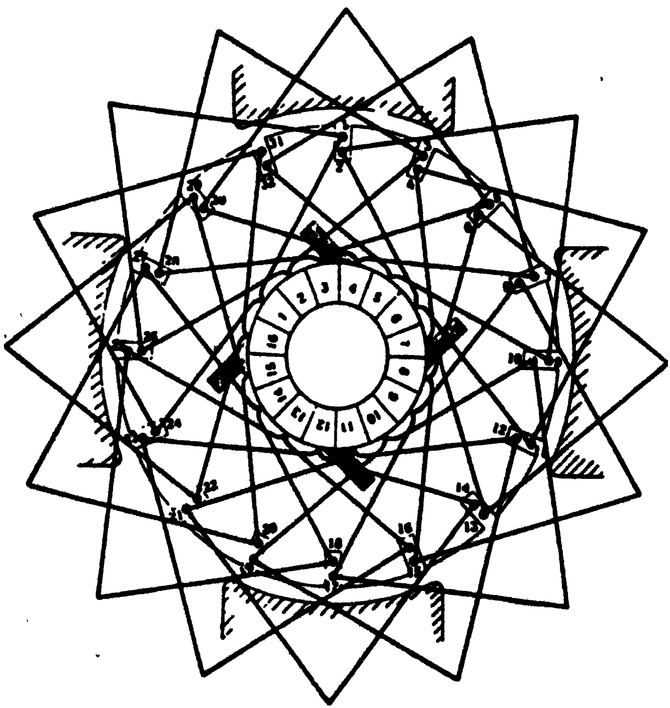


FIG. 13.—Four pole, 16 slot, multiplex lap winding.

The winding shown in fig. 14 has 26 slots and 4 poles with only alternate slots filled.

The back pitch y_b is *13*, and coil element *1* connects to element *14* and then connects to *5* on the front of the armature, making the front pitch y_f = 9.

Instead of returning to the element differing by 2 from the initial element, the return is made to a coil side differing by 4. It should be noted that the alternate slots and commutator segments are left vacant. Also this winding closes on itself after passing once around the armature.

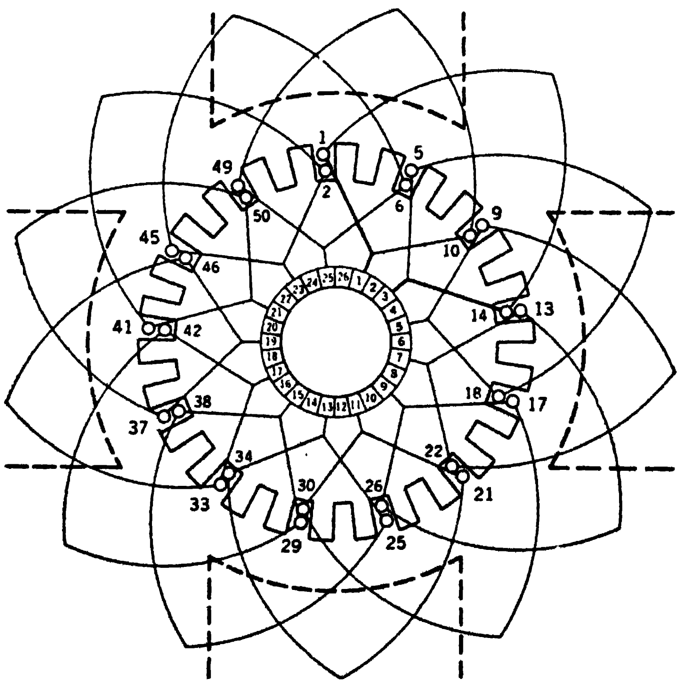


FIG. 14.—Illustrating a four pole, 26 slot, multiplex lap winding (only one winding shown)

In an armature wound in this manner a duplicate winding could be placed in the vacant slots. This additional winding would also close itself. These two windings would then be separate from each other on the armature, but connected in the same manner as the winding shown and to its proper commutator segment.

A multiplex lap winding in which the coil pitch is considerably less than the pole pitch is shown in fig. 15. In this case $s = 64$, $b = 12$ and $p = 2$. The number of slots $= 16$. Then:

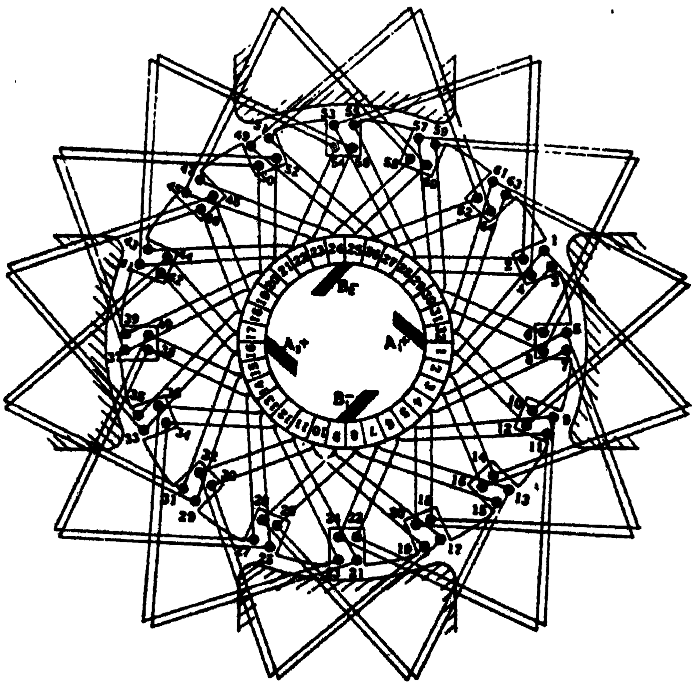


Fig. 15.—Four pole, 16 slot, multiplex lap winding.

$$y_b = \frac{64 - 12}{4} = 13$$

and

$$y_f = 13 - 2 = 11.$$

This type of winding is generally known as a chord or chorded winding in distinction from the full pitch winding.

A duplex lap winding composed of 36 coils placed in 18 slots and 18 coils for each winding, is shown in fig. 16. Here, $s = 72$, with the number of commutator bars $= 36$; $p = 2$, $m = 2$. Since in this case $s/2p$ is an even number $= 18$, b is taken as 4.

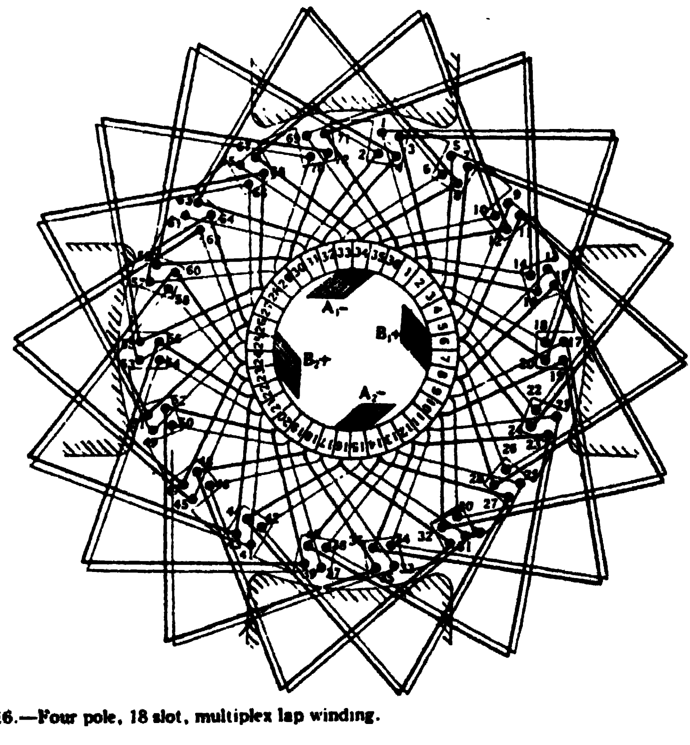


FIG. 16.—Four pole, 18 slot, multiplex lap winding.

Therefore:

$$y_b = \frac{72 - 4}{4} = 17$$

$$y_f = 17 - 4 = 13$$

and commutator pitch $y_c = \dfrac{17 - 13}{2} = 2.$

Since the number of commutator bars = 36 and the commutator pitch $y_c = 2$, have the common divisor 2, two distinct windings are obtained. Beginning with bar *1* and tracing through the winding, it may be seen that the winding completes itself after going around the armature once and connecting to one-half of the commutator bars; this winding has $2p = 4$ parallel circuits. Similarly the second winding embraces one-half of the coils and commutator bars, its coil fitting in between those of the first winding, and has also four parallel circuits. Therefore, the two windings together give eight parallel circuits.

Another duplex lap winding is illustrated in fig. 17. Here one of the two distinct windings is shown dotted for the sake of clarity. It should be noted that this winding does not close after passing once around the armature, but must pass around the armature once more before closing as indicated. The winding does not return to commutator segment number 1, but terminates at commutator segment number 2. The second winding shown with dotted lines starts at segment number 2 and closes at segment number 1 after passing once around the armature.

Single and Double Re-Entrant Windings.—The difference between a single and double re-entrant winding may best be illustrated with reference to figs. 18 and 19. When each of the two windings passes twice around the armature but closes only once, it is termed single re-entrant. When each of the two windings closes upon itself, the winding is termed double-re-entrant. With this latter type of winding it is necessary that the brush span at least two commutator segments.

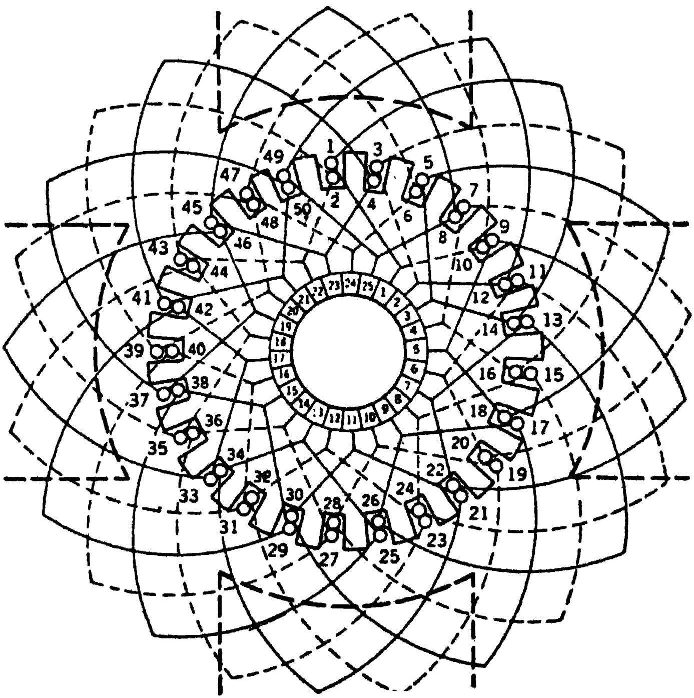
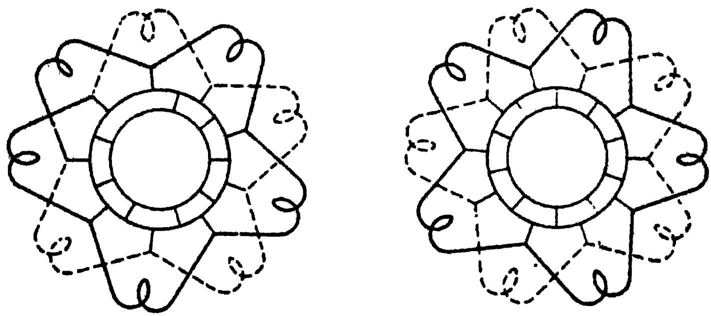


FIG. 17.—Four pole, 25 slot, multiplex lap winding.



FIGS. 18 and 19.—Schematic illustration of a duplex single and double re-entrant winding, respectively.

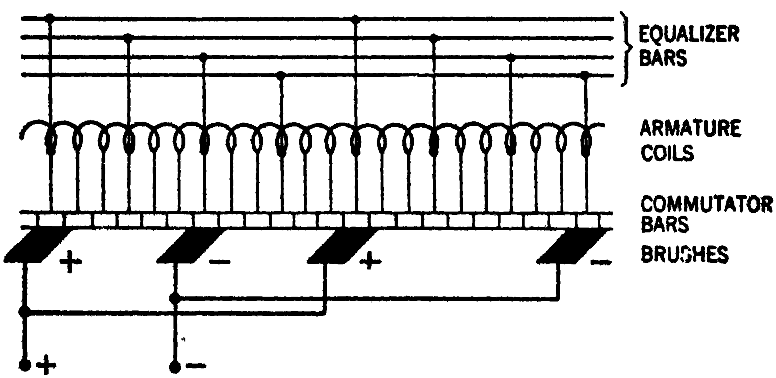


FIG. 20.—Schematic diagram of equalizer circuit showing four of six brushes.

Equalizer Connections in Lap Windings.—These are provided in parallel wound armatures to eliminate the effects of "unbalancing" by which the current divides unequally among the several paths through the armature. To relieve the brushes of this extra current, several points in the armature which should be simultaneously at the same potential are connected together as in fig. 20 by heavy copper bars termed equalizers, thus allowing the circulating currents to flow from one point in the armature to another without passing through the brushes.

If there were perfect symmetry in the field system of a machine, no current would flow along such connectors. Owing to imperfect symmetry, the induction in the various sections of the winding may be unequal and the current not equally distributed.

To exactly equalize the current, every commutator segment should have an equalizer connection. This would require a large number of connectors, but in practice only enough equalizer connections are made to keep variations in brush current within the limit required by the danger of sparking.

Wave Windings

General.—Whereas *lap windings* are generally used in machines required to carry a high current at low voltage, *wave windings* are used mainly where the current is low and the voltage is of a higher value.

The term *wave winding* (also called series or two-circuit winding) is derived from the wave path the winding takes through the slots of the armature, as illustrated in figs. 21 and 22.

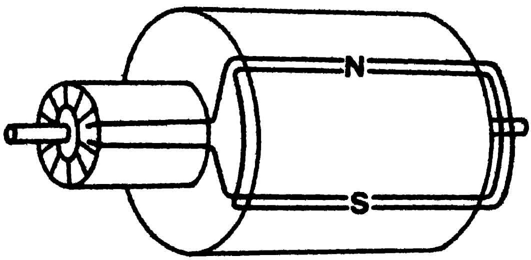


FIG. 21.—Wave winding showing the relative position of one winding element (or coil side) of two turns on the armature of a four pole machine.

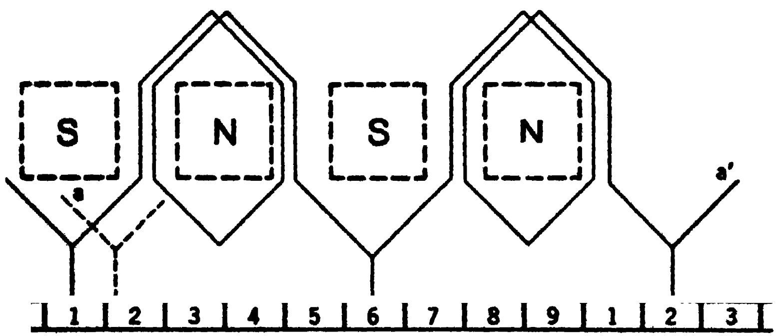


FIG. 22.—Illustrating wave winding diagrams of a four pole armature such as that given in fig. 21. It will be observed that the finish end of one coil is joined to the commutator bar and connected to the start of the next coil under the adjacent pair of poles. In the illustration *a* is a continuation of *a'*.

Tracing a Simplex Wave Winding.- A typical diagram of a simplex wave winding is shown in fig. 23. A tracing of the circuit shows that starting at brush *B*, and passing successively through conductors *11*, *16*, *3*, *8*, *13* and *18*, brush *A* is reached and that the *e.m.f.*'s in each of these conductors is in the opposite direction of travel of the point which traces out this path. Again starting at brush *B*, and passing successively through conductors *6*, *1*, *14*, *9*, *4*, *17*, *12* and *7*, the brush *A* is reached. This series of conductors are forming the second path between the brushes.

It follows that brush *B* is positive and brush *A* is negative as marked in our diagram.

It should be noted that in an actual machine there are several times as many conductors as shown in our simplified diagram. The principles, however, remain the same. This winding requires only two brushes irrespective of the number of poles in the machine.

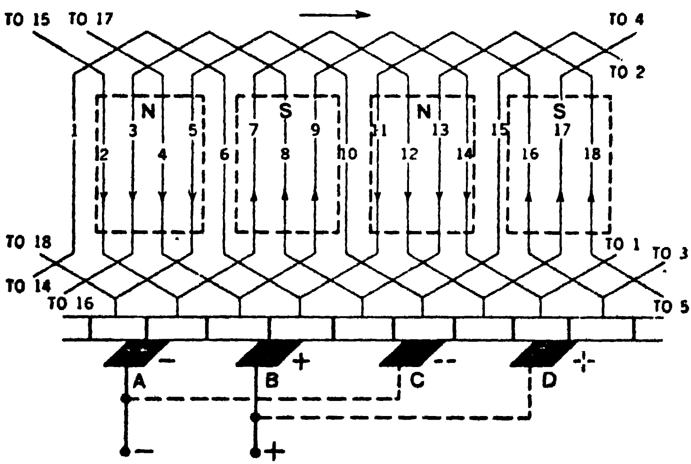
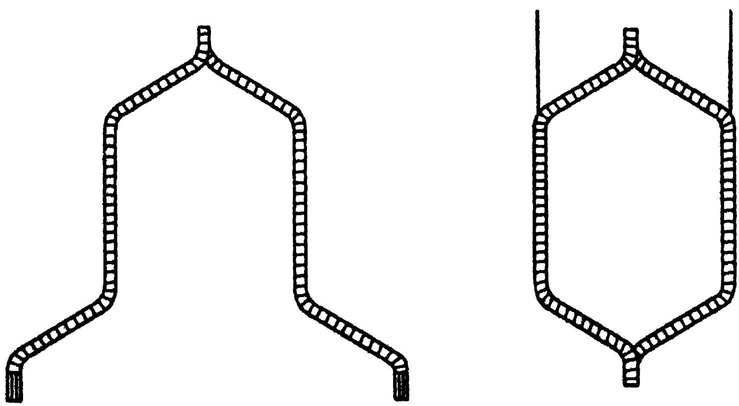


FIG. 23 —Showing a simplex, four pole, wave winding.

If it is desired, as many brushes as there are poles may be used; thus, with reference to fig. 23, a second positive brush *D* may be employed, connected to brush *B*, and also a second negative brush *C* connected to brush *A*. It may be observed that between brushes *B* and *D* there are only two armature conductors, *6* and *1*, in which there is practically no induced *e.m.f.*'s; hence the external connections between *B* and *D* does not short circuit any of the active conductors. Similarly, between brushes *A* and *C* there are the conductors *5* and *10*, or *2* and *15*, in which there is practically no induced *e.m.f.*'s or at least would not be in an actual machine having a large number of conductors.

Wave wound coils, figs. 24 and 25, as lap wound coils may have more than one turn, but since the number of turns does not affect the form of the winding, all wave windings are shown as having only one turn.



FIGS. 24 and 25.—Illustrating type of coils used in wave windings.

Symbols Used in Wave Windings.—In wave windings, as in lap windings, the number of elements spanned on the pulley end is termed the back pitch y_b and the number of elements spanned at the commutator end is termed the front pitch y_f.

This is illustrated in fig. 11. It should be observed here that the pitch is always forward in contrast to the lap winding where it is alternately forward and backward.

With reference to fig. 11, the following formulae are obtained:

$$\text{Winding pitch} = y = y_b + y_f = \frac{s \pm 2}{p} = 2\, y_c \tag{9}$$

$$\text{Commutator pitch} = y_c = \frac{y_b + y_f}{2} = \frac{k \pm 1}{p} \tag{10}$$

Where y = winding pitch.
y_b = back pitch.
y_f = front pitch.
s = the number of half coils or elements in the winding.
p = number of pairs of poles in the machine.
y_c = commutator pitch.
k = number of commutator bars in the machine.

It follows from the foregoing that the number of commutator bars must satisfy the equation:

$$k = p \times y_c \pm 1 \tag{11}$$

As before y_b and y_f must be odd integers and y must be a whole number. In this case the back pitch is very nearly equal to the pole pitch and the sum of the front and back pitches is very nearly equal to double the pole pitch. If y_b is decreased as in the case of a chord winding, then y_f must be increased so that the sum $y_b + y_f$ remains constant.

A four-pole wave winding having 13 coils is shown in fig. 26. Here $y_c = 6$ and $p = 2$. Then with reference to equation (12) $k = 2 \times 6 \pm 1 = 11$ or 13 (in this case, 13) and $y_b + y_f = 2y_c = 12$, for $k = 13$, $s = 26$, $y_b = 7$ and $y_f = 5$.

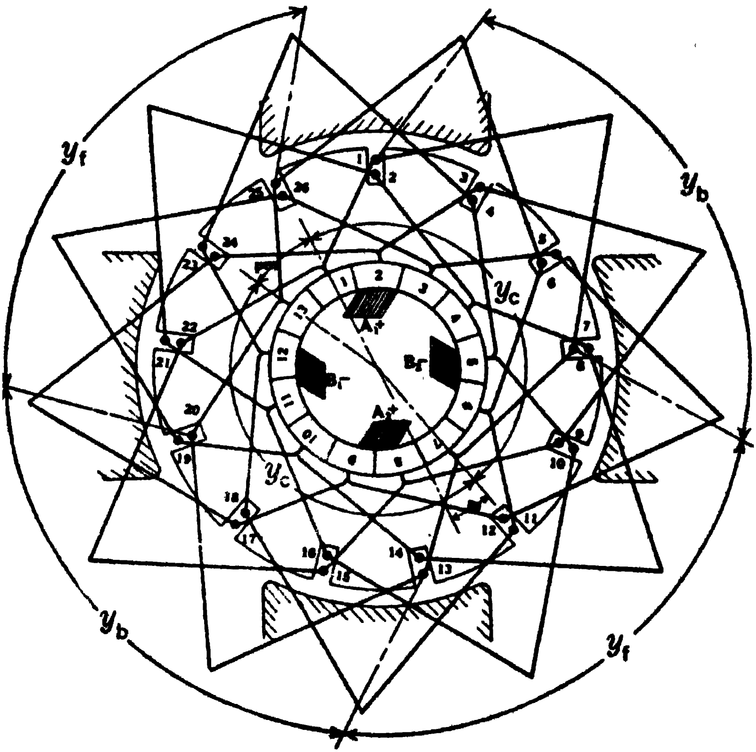


FIG. 26.—Illustrating a four pole wave winding.

Beginning with bar number *1*, it connects with ($1 + y_b = 1 + 7 = 8$), elements *1* and *8* forming the two sides of a coil. As the commutator pitch is ($y_c = 6$) and the front pitch *5*, from element number *8* the circuit passes across the front end of the armature to elements ($8 + 5 = 13$) and in so doing connects to commutator bar ($7 + y_c = 13$), the circuit is found to have traveled around the commutator a distance of $2y_c$ bars and have reached the bar ($1 + py_c$), at a distance of one bar from the starting point.

Denoting by m, the amount which y_c differs from the double pole pitch (in this case, half a bar), $pm = 1$ is the amount by which py_c or ($2y_c$) deviates from the starting point, bar number *1*. Then $py_c = k \pm pm$, or since, $m = a/p$; $y_c = \dfrac{k \pm a}{p}$, where a is the number of pairs of parallel circuits in the armature.

In this type of winding the number of parallel circuits in the armature is *two* regardless of the number of poles. A winding of this type is particularly well adapted for small and moderate-sized machines where it is desirable to keep the number of coils as small as possible.

Fig. 27 illustrates a 17-slot four-pole simplex wave winding. Here $y_b = 9$ and $p = 2$, $y_f = 7$, then $y_c = 8$. $k = 2 \times 8 \pm 1 = 17$ or 15 (in this case, 17).

A wave winding may be *duplex*, *triplex*, or have any degree of multiplicity in the same manner as the lap winding. A simplex wave winding always has two paths, a duplex wave winding four paths, etc., through the armature.

Fig. 28 illustrates a 26-slot four-pole winding in which only every alternate slot is filled, there are two coil sides per slot.

Here $y_b = 13$ and coil side *1* connects to the coil side *14* on the back of the armature. Coil side *14* then connects to *25* on the front of the armature, making the front pitch $y_f = 11$. Therefore, the commutator pitch $y_c = 12$. It should be observed that if the number of slots were 24 instead of 26 the winding would not have filled the alternate slots and closed, but would

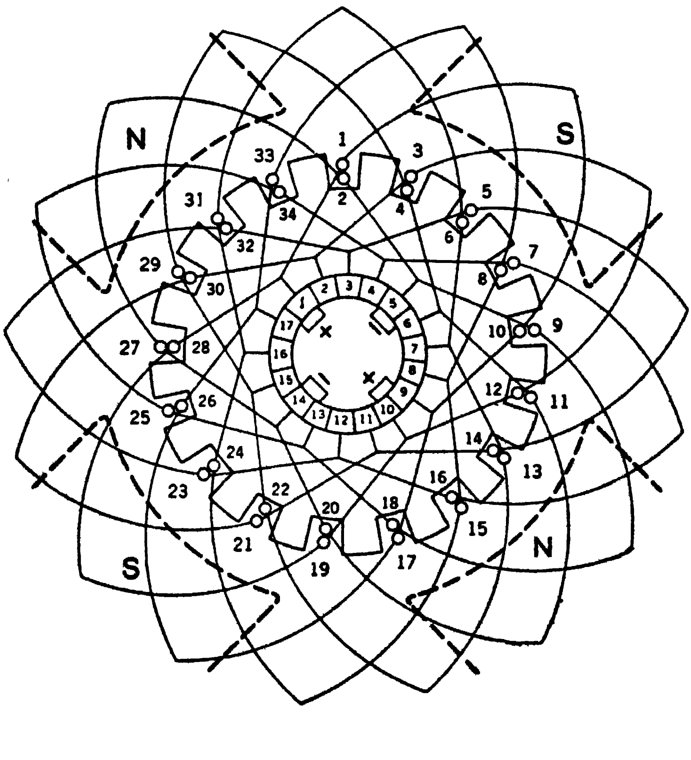


FIG. 27.—Four pole wave winding.

have returned to a slot and commutator segment to the right or left of the one from which it started. In this case the winding will close only after the remaining alternate slots are filled.

A winding of this latter type is illustrated in fig. 29, and is classified as a *duplex single re-entrant retrogressive* wave winding.

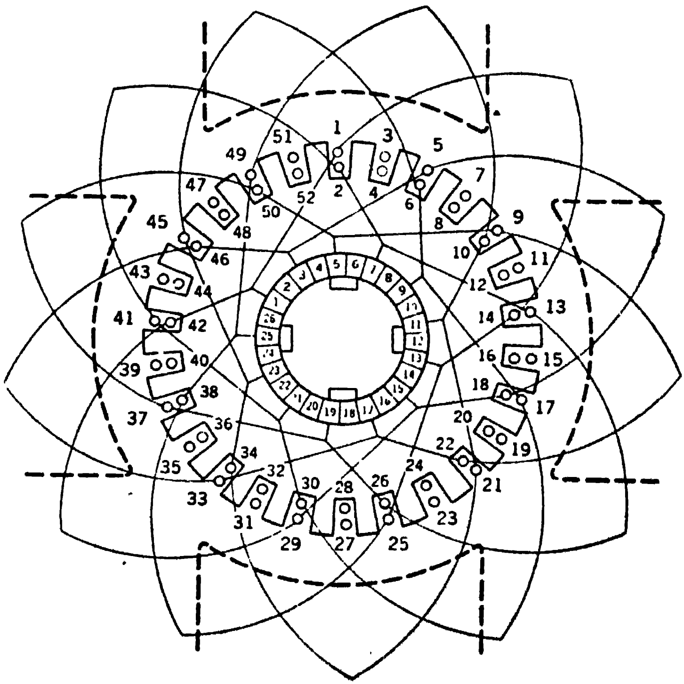


FIG. 28.—Four pole, 26 slot, wave winding.

It follows from this, that the multiplicity and re-entrancy for lap windings also applies for wave windings, that is, in a wave winding, multiplicity relates to the number of independent windings on the armature, whereas re-entrancy relates to the fraction of the armature that must be traced before returning to the commutator segment from which the winding began.

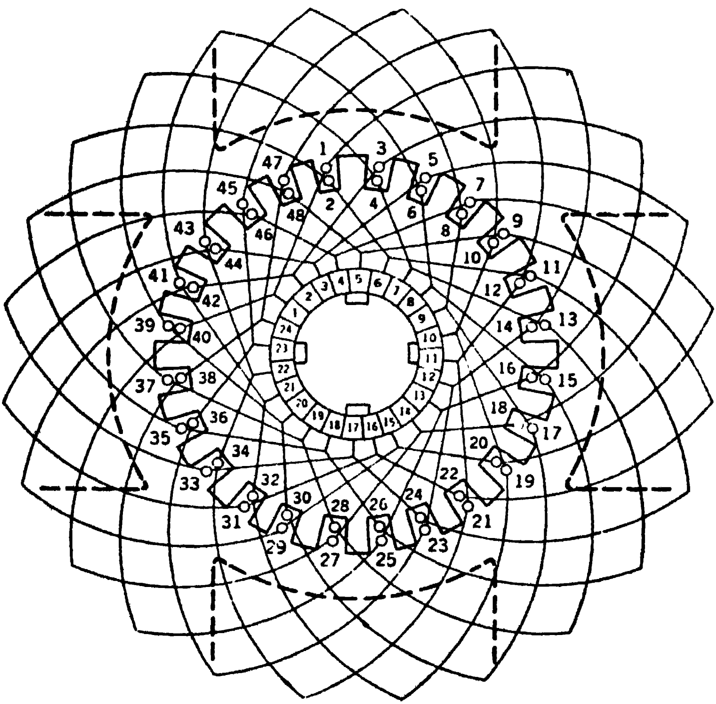


Fig. 29.—Four pole, 24 slot, wave winding.

Practically all of the important armature windings for large and moderate sized direct current machines are covered by the foregoing.

Comparison of Lap and Wave Windings.—As previously noted a wave winding has the advantage that it gives a higher voltage than the lap winding with a given number of poles and armature conductors. The wave winding is used in small machines and particularly those designed for higher voltages. To obtain a high voltage with a lap winding, the winding would result in a very large number of very small conductors. Another advantage in using the wave winding is that no equalizer connections are necessary.

When a machine is required to carry a heavy current at a low voltage, the lap winding is more satisfactory since this winding gives a larger number of paths.

TEST QUESTIONS

1. *What is the difference between the front and back of an armature?*
2. *Describe three kinds of winding diagrams.*
3. *How are inductors represented in the radial diagram?*
4. *What is the feature of the radial diagram?*
5. *What is a winding table?*
6. *How is a winding table used?*
7. *What two distinct methods are employed in armature winding?*
8. *What is the difference between a lap and a wave winding?*
9. *What is angular pitch and how is it determined?*
10. *What is commutator pitch?*
11. *What other name is given to lap winding?*
12. *Describe a simple lap winding.*
13. *What is the general form of the completed winding?*
14. *Describe in detail wave winding.*
15. *What other name is given to wave winding?*
16. *What is a double winding?*
17. *What is a diametrical or Siemens winding?*
18. *What is the objection to the diametrical winding and how avoided?*
19. *Describe the chord winding.*
20. *What name is sometimes given to the chord winding?*

21. *How does a diametrical winding differ from a chord winding?*
22. *Describe a multiplex winding.*
23. *What is the object of a multiplex winding?*
24. *For what service are multiplex windings used?*
25. *How is the required number of brushes obtained?*
26. *How many brushes are required for: a, lap windings; b, wave windings?*
27. *Are more than two brushes ever used for wave windings?*
28. *What are equalizer rings?*
29. *What points are connected by equalizer rings?*

CHAPTER 20

Armature Calculations

In the design of a dynamo or motor, it is usual to first design the armature and make the other parts fit around it

Accurate design is a matter of both calculation and experiment because many of the factors involved cannot be determined by calculation alone.

The principal item to be considered is the size of the wire.

In order to deliver a certain current, the number of poles, etc., being fixed, a certain size wire must be used. As must be evident, the heating of the wire is what governs the size. For a given current the smaller the wire, the greater the heating.

Example in Design.—Determine size of wire, number of turns, etc., for an 8×8 in. armature, for a flux of 30,000 lines per sq. in., 110 volts, 1,200 *r.p.m.*, 5 horse power.

Cross sectional area of armature = 8×8 = 64 sq. ins.

Total flux through armature = 30,000×64 = 1,920,000 lines.

Now, since it requires 10^8 or 100,000,000 lines of force cut per second to generate one volt, for the given 110 volts, the required rate of cutting is

$$\frac{\text{required rate of cutting}}{\text{total flux}} = \frac{110 \times 100\,000{,}000}{1{,}920{,}000} = 5{,}729 \text{ lines per sec.}$$

The number of inductors (wires) necessary to place on the armature to cut 5,729 lines per second will depend on the speed, thus

$$\text{number of inductors} = \frac{\text{total lines per wire per sec.}}{\text{revolutions per sec.}} = \frac{5{,}729}{{}^1\!/_{60} \text{ of } 1{,}200} = 286$$

For five horse power, at 110 volts

$$\text{watts} = 746 \times 5 = 3{,}730; \text{ amperes} = \frac{3{,}730}{110} = 34$$

TABLE II.—1 sq. in.

Capacity of Wires at various depths of winding, 1 sq. in. radiating surface per watt

(According to Horstmann and Tousky)

B. & S Gauge.	Diameter bare.	Resistance per foot 140° F.	Diameter D. C. C.	Amperes at different depths of winding layers.						Number of wires per inch.	I^2
				1	2	3	4	5	6		
4	.2043	.000283	.224	56.28	39.74	32.42	28 12	25.15	22.97	4.45	3166
5	.1819	.000357	.200	47.30	33.46	27.33	23.66	21.16	19.31	5.00	2240
6	.1620	.000450	.180	40.00	28.28	23.08	20.00	17.88	16.34	5.5	1600
7	.1413	.000567	.158	33.40	23.60	19.28	16.67	14.93	13.63	6.3	1114
8	.1285	.000715	.144	28.35	20.04	16.37	14.17	12.68	11.57	7.0	805
9	.1144	.000902	.130	24.00	16.97	13.85	12.00	10.72	9.74	7.7	576
10	.1019	.001137	.117	20.27	14.31	11.70	10.14	9.05	8.24	8.6	411
11	.0907	.001436	.106	17.19	12.12	9.69	8.60	7.68	7.00	9.6	295
12	.0808	.00181	.093	14.31	10.09	8.24	7.14	6.40	5.83	10.7	205
13	.0719	.00228	.084	12.12	8.54	7.00	6.08	5.38	4.89	11.9	147
14	.0640	.00288	.075	10.19	7.21	5.91	5.09	4.58	4.12	13.3	104
15	.0570	.00362	.067	8.60	6.08	4.95	4.30	3.87	3.50	15.0	74
16	.0508	.00458	.059	7.14	5.04	4.12	3.57	3.19	2.91	17.0	51
17	.0453	.00575	.053	6.08	4.30	3.5	3 04	2.64	2.47	19.0	37
18	.0403	.00727	.048	5.09	3.60	2.94	2.54	2.28	2.08	21.0	26
19	.0358	.00916	.044	4.36	3.08	2.52	2.18	1.97	1.7[illegible]	23.7	19
20	.0319	.01153	.040	3.74	2.64	2.16	1.87	1.67	1.52	25.0	14
21	.0284	.01454	.036	3.14	2.22	1.81	1.57	1.39	1.28	28.0	9.9
22	.0253	.01845	.033	2.66	1.87	1.54	1.33	1.19	1.09	30.8	7.1
23	.0225	.0231	.030	2.28	1.61	1.30	1.14	1.01	.94	33.3	5.3
24	.0201	.0295	.028	1.94	1.37	1.14	.97	.86	.80	35.7	3.8
25	.0179	.0365	.026	1.70	1.18	.98	.85	.80	.74	38.4	2.9
26	.0159	.0461	.024	1.41	1.00	.82	.71	.63	.57	42.0	2.0
27	.0142	.0603	.022	1.18	.78	.68	.59	.53	.47	45.5	1.4
28	.0126	.0744	.021	1.04	.72	.60	.52	.47	.42	48.0	1.1
29	.0112	.0925	.020	.92	.65	.53	.46	.42	.38	50.0	.86
30	.0100	.1181	.018	.77	.54	.44	.38	.35	.31	56.0	.61

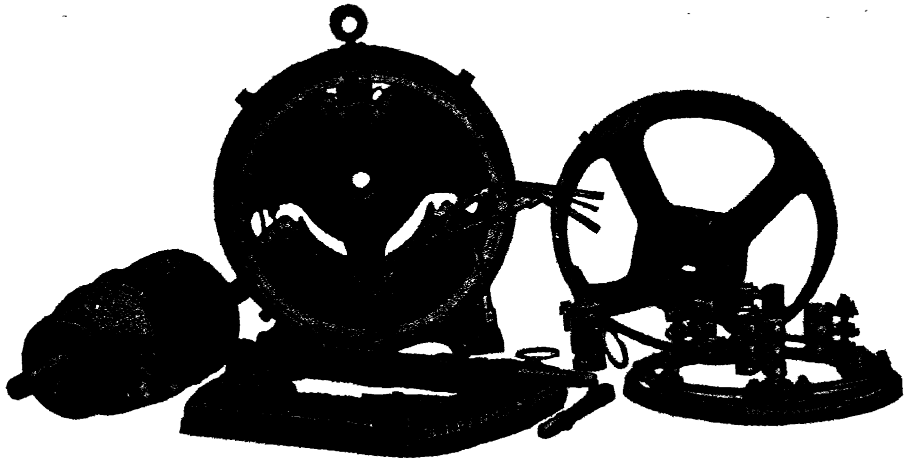


FIG. 580.—Fairbanks standard type TR machine disassembled.

Since there are two paths through the armature in parallel,

$$\text{amperes per circuit} = 34 \div 2 = 17$$

The size wire to be used is based upon a certan radiating surface per unit of energy consumed The greater this radiating surface, the less will be the heating. The amount of radiating surface allowed in armatures varies from 1 sq. in. per watt to 3 sq. ins. About 1.75 will insure a cool operating armature. In the accompanying tables, the current capacity is given for 3 sq. in. and for 1 sq. in. per watt. An inspection of the tables will show that the capacity of wires depends also upon the kind of winding—whether single layer or more than one layer—because radiation is more effective in carrying off the heat with outside wires than with those embedded under an outer layer of wires.

TABLE I.—3 sq. ins.

Capacity of Wires at various depths of winding, 3 sq. in. radiating surface per watt

(According to Horstmann and Tousley)

. & S. Gauge.	Diameter bare.	Resistance per foot 140° F.	Diameter D C C.	Amperes at different depths of winding layers.						Number turns per inch	1^2
				1	2	3	4	5	6		
4	.2043	.000283	.224	97.36	68.75	55.88	48.64	43.50	39.73	4.45	9498
5	.1819	.000357	.200	81 82	57.88	47.27	40.87	36.60	33.40	5.00	6720
6	.1620	.000450	.180	69.20	48.92	39 92	34 60	30.93	28.28	5.5	4800
7	.1413	.000567	.158	57 78	40.82	33.35	28.91	25.86	23 60	6.3	3344
8	.1285	.000715	.144	49.04	34 66	28.37	24.57	21.97	20.07	7.0	2416
9	.1144	.000902	130	41 52	29.37	24 00	20.76	18.60	16.97	7.7	1728
10	.1019	.001137	.117	35.06	24.81	20 27	17 54	15.71	14.35	8 6	1233
11	.0907	.001436	.106	29.74	21.02	17.17	14.86	13.30	12.12	9.6	885
12	.0808	.00181	.093	24.79	17.52	14 31	12.40	11.09	10 09	10.7	615
13	.0719	.00228	.084	21.00	14 86	12.12	10.50	9 38	8.54	11.9	441
14	.0640	.00288	.075	17.66	12.49	10.19	8.83	7.88	7 21	13.3	312
15	.0570	.00362	.067	14.89	10.53	8.60	7.44	6.66	6.08	15.0	222
16	.0508	.00458	.059	12.40	8.77	7.21	6.20	5.56	5 09	17 0	154
17	.0452	.00575	.053	10.53	7.44	6.08	5.26	4.71	4.30	19.0	111
18	.0403	.00727	.048	8.88	6.28	5.12	4.44	3.97	3.63	21.0	79
19	.0358	.00916	.044	7.54	5.34	4.35	3.76	3.37	3.08	22.7	57
20	.0319	.01153	.040	6.49	4.58	3.74	3.24	2.89	2.64	25.0	42
21	.0284	.01454	.036	5.38	3.80	3.11	2.68	2.40	2.19	28.0	29
22	.0253	.01845	.033	4 58	3.24	2.64	2.28	2.04	1.87	30.3	21
23	.0225	.0231	.030	4.00	2.82	2.30	2.00	1.78	1.64	33.3	16
24	.0201	.0295	.028	3.37	2 38	1.94	1.67	1.51	1.37	35.7	11.4
25	.0179	.0365	026	2.93	2.07	1.67	1.44	1.30	1.18	38.4	8.6
26	.0159	.0461	.024	2.49	1.76	1.41	1.22	1.09	1.00	42.0	6.2
27	.0142	.0603	.022	2.07	1.44	1.18	1.04	.94	.84	45.5	4.3
28	.0126	.0744	021	1.78	1.26	1.04	.89	.78	.71	48.0	3.2
29	.0112	.0925	.020	1.61	1 14	.94	.79	.71	.65	50.0	2.6
30	.0100	.1181	.018	1.34	.95	.78	.64	.60	.55	56.0	1.8

Now, since the diameter of the core is 8 ins.

its circumference = 8×3.1416 = 25 ins.

and the number of inductors per inch of circumference is

for single layer winding 286 ÷ 25 = 11.4
for double layer winding ½ of 286 ÷ 25 = 5.7

Allowing 1 sq. ins. radiating surface per watt, the size of inductor required to carry 17 amperes is (from Table II on page 392.)

for single layer winding, No. 11, B. & S. gauge
for double layer winding, No. 9, B. & S. gauge

Example.—With the armature of the previous example running at same speed and same flux conditions what is the maximum capacity that could be obtained with a two layer winding of larger size wire and same number of inductors? As calculated, the number of inductors per inch of core circumference is 5.7, hence, from table 1, for 5.5, inductors per inch a No. 6 wire may be used, and for a two layer winding it may carry 28.28 amperes. Now since there are two paths in parallel through the armature

total current = 2 × 28.28 = 56.6 amperes

and capacity at 110 volts, or

watts = 56.6 × 110 = 6,226

Since 1 horse power = 746 watts,

capacity = 6,226 ÷ 746 = 8.4 horse power

In the case of slotted armatures, which is the prevailing type, a considerable portion of the circumference is taken up with the teeth that cannot be used for the winding, hence it is necessary to allow for this in figuring the number of inductors per inch of circumference.

To calculate the size wire for a slotted armature a single slot should be considered, and the wire chosen if possible with reference as to how it will fit in the slot, that is, the size should be such as to fill the slot with the least amount of waste space. ***In design,*** the approximate width of the slot is obtained by *multiplying the diameter of the wire over insulation by the number of turns per layer*, and the depth of slot obtained by *multiplying the number of layers by* .86.

To find the number of inductors per slot when the speed and flux are fixed, the following formula may be used:

$$\text{inductors per slot} = \frac{10^8 \times \text{volts}}{\text{flux} \times \text{slots} \times \text{rev. per sec.}} \quad \ldots\ldots\ldots\ldots (1)$$

Example.—How many inductors per slot are required, to generate 110 volts, with a total flux of 1,920,000 lines, 24 slots and 1,200 revolutions per minute?

$10^8 = 100,000,000$
and
1,200 rev. per minute =
$1,200 \div 60 = 20$ rev. per sec.
Substituting in (1)

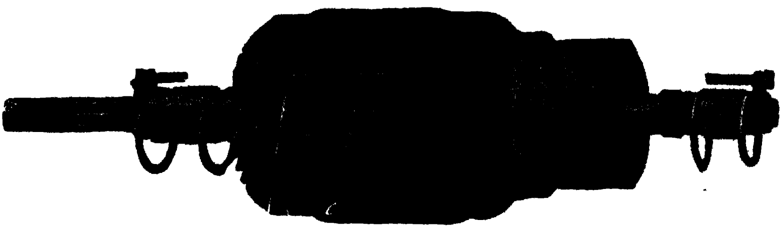


FIG. 581.—Fairbanks Morse type TR machine armature construction. *The armature core*, is built up of thin sheet steel laminations with notches in the circumference, which, when the discs are placed together, form grooves or slots to receive the armature coils. With specially designed tools these notches are so accurately spaced that no filing of the slots is required. The armature cores for the Nos. 23, 24, 25, 26, 27, 28 and 29, machines are mounted on a cast iron spider, which also carries the commutator, making the two parts entirely self-contained, and with this construction, it is possible to remove the armature shaft, without disturbing the core, commutator or windings.

$$\text{inductors per slot} = \frac{100,000,000 \times 110}{1,920,000 \times 24 \times 20} = 12$$

Example.—If the slots of a 24 slot armature be ½ in. wide, and there be 12 inductors per slot arranged as a three layer single coil winding, what is the maximum size wire that can be used, and current capacity for a four pole machine? If flux be provided to generate 110 volts what horse power will be developed?

Table 3 gives relation between slot sizes and various practical arrangements of standard double cotton wires B. & S. gauge. Allowance is made in the slot widths for ⅛ in. total insulation besides the cotton wrapping on the wire, when there is only one coil per slot.

For each additional coil per slot, ⅛ in. of extra insulation is allowed. In slot depths, .17 in. beside the cotton on the wire is provided.

In the example since there are 12 inductors per slot and the winding is in 3 layers

$$\text{number of wires abreast} = 12 \div 3 = 4$$

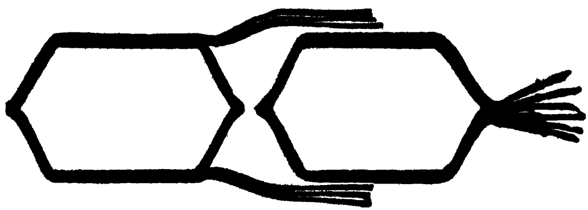
Referring to the table it will be found that a slot .42 in. wide will accommodate four No 10 inductors abreast. Allowing 1 sq. in. radiation per watt, the carrying capacity (from table No. 2) for a 3 layer winding of No. 10 wire is 11.7 amperes.

Since the number of paths is equal to the number of poles

$$\text{total current output} = 11.7 \times 4 = 47 \text{ amperes}$$

At 110 volts

$$\text{watts} = 47 \times 110 = 5{,}170, \text{ and}$$
$$\text{horse power} = 5{,}170 \div 746 = 6.9$$



FIGS. 582 and 583.—Fairbanks Morse wire wound armature coils of type Tr machine. *In construction*, the coils are form wound and are thoroughly insulated and baked before assembling in the slots. Material of great mechanical strength as well as high insulating value is used, and the coils are subjected to repeated dippings in insulating compound and to repeated bakings, thus thoroughly driving out all moisture and making a coil which is practically water proof and which will withstand rough handling. These coils when completed, are placed in the slots, where they are retained by bands on the three smaller sizes and by hardwood wedges on the larger sizes. Cores of all sizes are provided with ventilating spaces, running from the surface to the central opening of the core, so that air is drawn through the core and blown out over the windings by the revolution of the armature.

After having determined the size of wire, number of turns per coil, the drop or loss voltage due to the resistance of the winding should be determined to see if this loss be within limit.

Example.—If the average length per turn of the coils in the armature of the previous example be 2 ft., what is the drop or loss of voltage in the armature?

Since the winding is of the single coil type each coil will occupy two slots, hence

$$\text{total number of coils} = 24 \div 2 = 12$$

For 12 turns per coil,

$$\text{length of each coil} = 12 \times 2 = 24 \text{ ft.}$$

Now, since the machine has 4 poles, there are 4 paths in parallel, hence, only ¼ of the coils or 3 coils need be considered in determining the drop. Accordingly,

$$\text{length of 3 coils} = 24 \times 3 = 72 \text{ ft.}$$

According to table 1 (page 390), the resistance of No. 10 wire at 140° Fahr. is .001137 ohm per foot, hence

$$\text{resistance of 3 coils} = 72 \times .001137 = .08 \text{ ohm}$$

According to Ohms law

$$\text{current} = \frac{\text{volts}}{\text{ohms}}, \text{ or volts} = \text{current} \times \text{ohms}$$

Substituting in the expression for volts,

$$\text{volts or "drop"} = 11.7 \times .08 = .94 \text{ volt}$$

which may be considered within satisfactory limit.

Magnet Calculations.—In figuring field magnets, the unit ampere turn is frequently employed and is defined as *the magnetic force due to a current of one ampere flowing through one turn of a*

NOTE.—*To find the speed* when the volts, flux, and number of inductors are fixed, use this formula:

$$\text{rev. per sec.} = \frac{100{,}000{,}000 \times \text{volts}}{\text{flux} \times \text{number of slots} \times \text{inductors per slot}}$$

NOTE.—*To find the strength of field* when the volts, inductors and speed are, fixed, use the formula:

$$\text{flux} = \frac{100{,}000{,}000 \text{ volts}}{\text{inductors per slot} \times \text{number of slots} \times \text{rev. per sec.}}$$

NOTE.—*To find the volts* when the inductors, flux, and speed are fixed use the formula:

$$\text{volts} = \frac{\text{flux} \times \text{inductors per slot} \times \text{number of slots} \times \text{rev. per sec.}}{100{,}000{,}000}$$

magnet winding; numerically it is equal to the ***product of one turn multiplied by one ampere.***

Thus, one ampere flowing through 10 turns, gives 1 × 10 = 10 ampere turns. Again, 10 amperes flowing through 10 turns gives 10 × 10 = 100 ampere turns. Having fixed the voltage and size of wire it makes no difference in the magnetic effect how many turns are contained in the winding, that is, for a given voltage and size of wire ***the ampere turns remain the same regardless of the number of turns in the winding.***

Thus, if 10 amperes flow through 10 turns of the winding the result is 10 × 10 = 100 ampere turns. Now, if the number of turns be doubled, the resistance of the winding will be doubled which will cut down the current one half, that is, 5 amperes × 20 turns = 100 ampere turns. Of course, this is not strictly true where the magnet is made up of more

FIG. 584.—Fairbanks Morse field coils of type Tr machine. ***In construction,*** the coils are wound upon iron forms, each layer treated with insulating compound. Afterward they are removed from the forms and baked hard and dry and finally wrapped with insulating materials and finished with black insulating enamel.

than one layer, because the diameter of an outer turn being greater than that of an inner turn, its length and resistance is greater, the resulting effect being to slightly decrease the ampere turns as each layer is added. The reason then for increasing the number of turns in a magnet winding is ***to cut down the current sufficiently to prevent overheating of the winding.***

Example.—If the winding on a spool 8 ins. in diameter be one inch thick, what is the average diameter of the turns?

The diameter of the inner layer turns is 8 ins., and the outer layer turns, 8 + 2 = 10 ins., hence,

$$\text{average diameter of the turns} = \tfrac{1}{2}\,(8 + 10) = 9 \text{ ins.}$$

Example.—If the magnet of the previous example contain 500 turns, what is the length of the winding?

The average diameter of the turns, as obtained, being 9 ins.

$$\text{length of winding} = \frac{9 \times 3.1416 \times 500}{12} = 1{,}178 \text{ ft.}$$

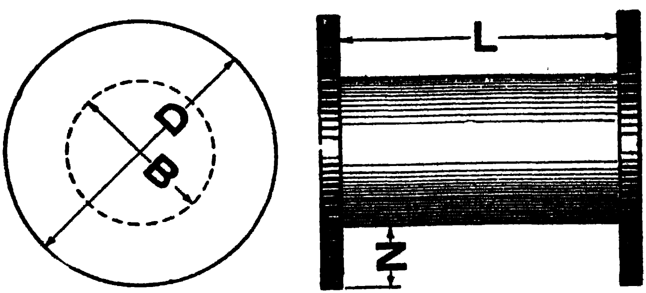
Example.—If a winding one inch deep be placed on an 8 in. spool, what is the smallest size wire that will give 10,000 ampere turns with 110 volts?

$$\text{average diameter of turns} = \tfrac{1}{2}\,(8 + 10) = 9 \text{ ins.}$$

$$\text{length of average turn} = \frac{9 \times 3.1416}{12} = 2.36 \text{ ft.}$$

The sectional area of the smallest wire (in circular mils) is obtained from the formula

$$^{*}\text{area wire} = \frac{12 \times \text{length average turn in feet} \times \text{ampere turns}}{\text{volts}} \quad \ldots\ldots\ldots\ldots (1)$$



FIGS. 585 and 586.—Magnet spool with essential dimensions necessary for calculation. ***Formulae:*** $d = \sqrt{(L \times N) \div T}$; $L \times N = d^2 \times T$; $l = (D^2 - B^2)L = k$; $W = (D^2 - B^2)L \times c$; $R = (D^2 - B^2)\ L \times a$; $rs = D \times 3.14 \times L$. In the formulæ, d = diam. of wire over insulation; l = length of wire on spool; T = number of turns; r = resistance of one foot of wire; rs = radiating surface; B = diam. of core and insulation; D = diam. over outside of completed winding; L = length of winding space on spool; N = depth of winding core to outside; W = weight of wire; a, c, k, constants whose values are given on page 399. All dimensions are in inches.

Substituting

$$\text{area wire} = \frac{12 \times 2.36 \times 10{,}000}{110} = 2{,}575 \text{ circular mils}$$

nearest size wire from table is No. 16 B. & S. gauge.

Having determined the minimum size of wire, the next step

*NOTE.—In the formula, 12 is the resistance of 1 mil foot of copper at 180° Fahr.

is to find how many turns must be placed on the spool to prevent undue heating.

The watts lost by the current heating the winding *is equal to the square of the current multiplied by the resistance*, that is

$$\textit{watts lost} = \textit{amperes}^2 \times \textit{ohms}.$$

Table of Constants

B. & S. Gauge	k Constant for Length.			C Constant for Weight.			G Constant for Resistance.		
	Double Cotton	Single Cotton	Single Silk	Double Cotton	Single Cotton	Single Silk	Double Cotton	Single Cotton	Single Silk
20	40.9	50.4	56.7	.137	.162	.177	.415	.512	.576
21	50.4	64.1	72.7				.688	.812	.920
22	60.2	78.0	89.7				.97	1.257	1.445
23	68.3	89.7	104.7				1.287	1.82	2.08
24	88.6	113.5	136.	.1115	.149	.160	2.14	2.91	3.46
25	97.2	135.	168.				3.14	4.86	5.27
26	114.	168.	202.				4.65	6.65	8.34
27	136.	202.	255.				6.94	11.75	13.1
28	148.	226.	291.	.0845	.122	.148	9.60	14.62	18.82
29	182.	291.	387.				14.85	23.7	31.6
30	201.	334.	454				20.7	34.4	46.3
31	226.	387.	542				29.36	50.26	70.4
32	265.	454.	655.	.0687	.1045	.132	41.8	74.4	107.2
33	291.	542.	812.				60.33	114.5	168.
34	334.	655.	1022.				87.1	170.5	266.5
35	354.	712.	1140.				116.2	234.	374.8
36	387	811.	1340	.0492	.0825	.1115	160.	335.5	555.
37	422.	897.	1582.				220.5	468.	806.
38	457.	1023.	1825.				308.	674.	1192.
39	496.	1170.	2165.				412.	972.	1795.
40	522.	1300.	2625.	.038	.0615	.0838	557.	1360.	2645.

In proportioning the winding for depth and length, the depth of the winding must be such that there will be from 1 to 2 sq. ins. of surface per watt. With 1 sq. in. per watt, the magnet in operation will be "hot," and with 2 sq. ins., "warm."

Example.—How much radiating surface (neglecting the ends) on a magnet whose outside dimensions are 9 ins. diameter, 6 ins. long

area outer cylindrical surface $= 9 \times 3.1416 \times 6 = 169.6$ sq. ins.

Example.—An 8 in. spool is to be wound with No. 16 wire to a depth of 1 in., which, as calculated in a previous example, is the smallest size wire that will give a required 10,000 ampere turns with 110 volts. How many turns of wire must be wound on the spool to prevent undue heating?

For winding magnets what is known as *magnet wire* is used, the wire generally having a single cotton covered insulation.

By reference to the table on page 400, the number of turns per linear

TABLE III.—*Properties of Insulated Wires*

(According to Horstmann and Tousley)

B. & S.	Single silk		Double silk		Dble. cotton		Resistance	I^2 3 sq. in. per watt. Cool	I^2 2 sq. in. per watt. Warm	I^2 1 sq. in. per watt. Hot
	Turns per inch	Radiating Surface	Turns per inch	Radiating Surface	Turns per inch	Radiating Surface				
40	193	.016	143	.022	90	.035	.273	.027	.04	.08
39	181	.017	133	.024	87	.047	.216	.036	.055	.11
38	169	.018	126	.025	84	.037	.172	.046	.07	.14
37	156	.020	119	.026	81	.039	.136	.070	.10	.20
36	143	.022	111	.028	77	.041	.108	.086	.13	.26
35	131	.024	104	.030	73	.043	.075	.13	.20	.40
34	120	.026	97	.032	69	.045	.068	.15	.23	.46
33	111	.028	91	.035	66	.047	.054	.22	.32	.64
32	101	.031	83	.038	63	.050	.043	.29	.44	.88
31	91	.034	77	.041	59	.053	.034	.37	.56	1.12
30	83	.038	71	.044	55	.056	.027	.54	.81	1.62
29	76	.041	67	.047	53	.059	.022	.72	1.07	2.14
28	68	.046	60	.052	48	.065	.017	1.0	1.5	3.00
27	63	.050	55	.056	45	.069	.014	1.3	2.0	4.00
26	56	.055	50	.062	41	.075	.011	1.9	2.8	5.60
25	50	.062	46	.069	38	.081	.0084	2.7	4.1	8.2
24	45	.069	42	.075	35	.088	.0070	3.5	5.3	10.6
23	41	.077	37	.083	32	.095	.0053	5.2	7.8	15.6
22	36	.086	34	.092	30	.104	.0042	7.3	11.0	22.
21	33	.094	31	.101	28	.113	.0034	10.	15.0	30.
20	29	.106	27	.113	25	.126	.0026	14.	21.	42.
19	26	.119	25	.126	22	.138	.0021	20.	30.	60.
18	24	.132	22	.138	21	.151	.0017	27.	40.	80.
17	21	.148	20	.154	19	.166	.0013	39.	59.	118.
16	19	.166	18	.173	17	.185	.0011	52.	78.	156.
15			16	.191	15	.204	.00083	70.	105.	210.
14			15	.213	14	.226	.00066	107.	161.	322.
13			13	.238	12	.251	.00053	149.	224.	448.
12			12	.267	11	.279	.00042	217.	325.	650.
11			11	.298	10	.311	.00033	301.	451.	902.
10			9.5	.329	9.1	.342	.00026	421.	632.	1264.
9			8.4	.370	8.1	.383	.00021	587.	880.	1760.
8			7.5	.414	7.3	.428	.00016	842.	1262.	2524.
7			6.9	.455	6.8	.468	.00013	1167.	1750.	3500.
6			6.0	.521	5.8	.534	.00010	1680.	2521.	5042.

inch or per sq. in. of cross sectional area is obtained. Taking a portion of the winding covering an inch length of spool, 1 in. deep, the sectional area of this portion is 1 sq. in. Referring to the table of magnet wire, No. 16 wire single covered, will wind 361 turns per sq. in., that is, per inch length of spool. The length of the average turn being 2.36 ft. (as calculated in a previous example)

$$\text{length of winding per inch of spool} = 361 \times 2.36 = 852 \text{ ft.}$$

and from table its resistance being 4.009 ohms per 1,000 ft.

$$\text{resistance of winding per inch of spool} = \frac{852}{1{,}000} \text{ of } 4.009 = 3.42 \text{ ohms}$$

The outside diameter of the winding being 10 ins.,

$$\text{radiating surface per inch of spool} = 10 \times 3.1416 = 31.4 \text{ sq. ins.}$$

Now, in any electric circuit, the energy lost by heating the wire, or

$$\text{watts} = \text{amperes}^2 \times \text{ohms} \ldots\ldots (1)$$

but by Ohm's law

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

Substituting this value for amperes in equation (1)

$$\text{watts lost} = \frac{\text{volts}^2}{\text{ohms}^2} \times \text{ohms} = \frac{\text{volts}^2}{\text{ohms}}$$

And if the coil be designed for "warm" working by allowing 2 sq. in. radiating surface per watt, then it must be so proportioned that

$$\text{radiating surface} = 2 \times \text{watts lost} = 2 \times \frac{\text{volts}^2}{\text{ohms}} \ldots\ldots (2)$$

In order to determine the length of the coil, first find what resistance would be necessary if the winding were to consist of only the one inch portion just considered. To do this, solve equation (2) for resistance. thus

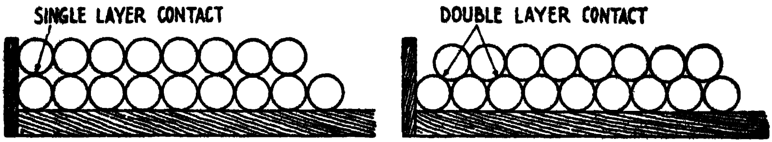
$$\text{ohms} = \frac{2 \times \text{volts}}{\text{radiating surface}} \ldots\ldots (3)$$

This will give a resistance much greater than the 3.42 ohms as calculated for that portion of the winding, hence, the spool length of the winding must be increased until the resistance of the winding has a value as obtained by equation (3). Thus, substituting in equation (3), 110 volts, and 31.4 sq. ins. radiating surface in equation (3), the necessary resistance of the winding for "warm" working, is

$$\text{ohms} = \frac{2 \times 110}{31.4} = 7$$

Accordingly, since the resistance of the winding is prooortional to its length,

$$\text{length of winding} = 1 \text{ in.} \times \frac{7}{3.42} = 2 \text{ ins.}$$



FIGS. 587 and 588.—Square and hexagonal order of "bedding." The term bedding is an expression used to indicate the relation between the cross sectional area of the winding when wound square, as in fig. 587, and when wound in some other way, as in fig. 588. In the square order of bedding, the degree of bedding equals zero.

NOTE.—*Number of armature slots.* As a rule there are not less than ten slots per pole. In multi-polar machines there are at least three or four slots in the space between adjacent pole tips. The area per slot on machines above five horse power is approximately one sq. in. and roughly the capacity of a slot of this area is about 1,000 ampere turns for machines designed to work on less than 500 volts.

NOTE.—*Number of commutator bars.* This depends on the voltage between the bars. The number of bars may be a multiple of the number of slots. A large number of commutator bars improves the commutation but this advantage is offset by increased difficulties encountered in construction.

NOTE.—*Current density in armature inductors.* In determining the intensity of current much depends upon the provision for ventilation and operating conditions. *In general,* 600 to 700 circular mils per ampere is safe. For short overloads or for operation in hot engine rooms, 1,000 circular mils per ampere may be used.

NOTE.—*Magnetic densities.* In small machines the density in the air gap is rarely over 32,000 lines per sq. in.; in large machines the density may be as high as 60,000 lines per sq. in. Density in teeth is usually about 100,000 lines per sq. in. being somewhat less in very small machines. *Density in magnet core:* cast iron may be worked up to about 40,000 or 50,000 lines per sq. in.; wrought iron and cast steel being about 95,000 to 105,000 or more lines per sq. in. Density in yoke: for cast iron the density should be about 30,000 lines per sq in.; for cast steel, about 75,000 lines, and for wrought iron forgings about 85,000 lines. *Density in armature core:* this may be taken at from 85,000 to 90,000 lines per sq in. for drum armatures

NOTE.—*Dynamo losses.* These are the mechanical losses due to friction, and electrical losses in the core, field and armature. *Friction loss.* This ranges from 3 to 5% in respectively small and large machines of good design. Core loss. In well designed machines this should not exceed 2% of the output at full load. *Field loss.* A portion of the electrical energy generated in the armature is lost in exciting the field magnets. *Armature loss.* This is usually termed the copper loss since it is due to the resistance of the winding; it is a very variable quantity and is equal to the square of the current multiplied by the resistance of a section of the winding between brushes.

NOTE.—*Armature paths in wave and lap windings.* A wave winding has but two paths through the armature, regardless of the number of poles; whereas a lap winding has as many paths as there are poles. This distinction is important in figuring the size of wire for the winding to carry the current without undue heating.

TEST QUESTIONS

1. *In re-winding an armature what problems must be solved by the repair man?*
2. *In what case are the difficulties indicated in Question No. 1 not encountered?*
3. *What is the usual procedure in designing a dynamo or motor?*
4. *What is the principal item to be considered?*
5. *How is the total flux through an armature determined?*
6. *How many lines of force must be cut per second to generate one volt?*
7. *How is the number of inductors calculated for a given output?*
8. *Upon what is the size of wire based?*
9. *What allowance for radiating surface is made per watt?*
10. *In the case of slotted armature what allowance must be made in figuring the number of inductors per inch of circumference?*
11. *What must be considered in calculating the size of wire for a slotted armature?*
12. *What should be done after making the various calculations?*
13. *How is the speed determined?*
14. *With volts, inductors and speed given, how is the strength of field determined?*
15. *With inductors, flux and speed given how is the voltage determined?*

16. *What is the basis for figuring field magnets?*
17. *After determining the minimum size of wire for field magnets, what is the next step?*
18. *Describe the calculation of a field magnet in full.*
19. *What are the usual magnetic densities?*

CHAPTER 21

Practical Armature Winding and Repairs. Shop Methods

The author is indebted to Mr. P. E. Chapman, of St. Louis, Mo., authority on armature windings, for considerable assistance in the preparation of this chapter.

The repair man and shop worker who must wind armatures will need additional information to that contained in the preceding chapter, which gives only an elementary treatment of the subject. In this chapter practical matters or shop methods are presented.

Armature Types.—There are a number of distinct types of armatures and each of these types uses different methods of winding.

The principal types are:

Bipolar.—Smaller or fractional sizes using wire from No. 20 B & S and finer nearly always wound by machine.

Medium sizes using wire to about No. 16 sometimes encountered in automotive work. Wound both by hand and machine.

Large bipolar trom 1 *h.p.* up seldom made over 3 *h.p.* occasionally machine wound, mostly hand wound, sometimes form wound and coils assembled

Four Pole.—Smaller armatures principally automotive using wires from No. 16 to No. 18 both hand and machine wound, usually random. Wound directly on the core, or prewound and coils assembled.

Larger types nearly always using preformed and more or less preinsulated coils.

Winding Data Required.—It is necessary to have winding data whether an armature be new or old no matter what the type. Much of this data reads the same for all armatures and is absolutely essential.

If the armature be old the data should be obtained before and while stripping off the old winding. The following is a list of the data required;

Maker's Name	Class	Type	Spec. No.
Voltage	Capacity	D.C. or A.C.	Phase cycles
Amperes	Speed		Armature or stator

Number of turns per coil — Size and covering of wire

Number of coils per bundle or slot

Number of teeth the coils go around (usually expressed as "8 teeth"), or

Number of the slots the coils go in (usually counted as one more than the enclosed number of teeth as "1 and 9")

Lead between the armature winding and the commutator

Number of poles — Insulation of core (if complex)

The above data applies to practically all types of armatures.

If the armature be form wound or multipolar the following should also be obtained:

Save a sample coil

Insulation on the coil (if formed)

Number of commutator bars.

Span of the leads

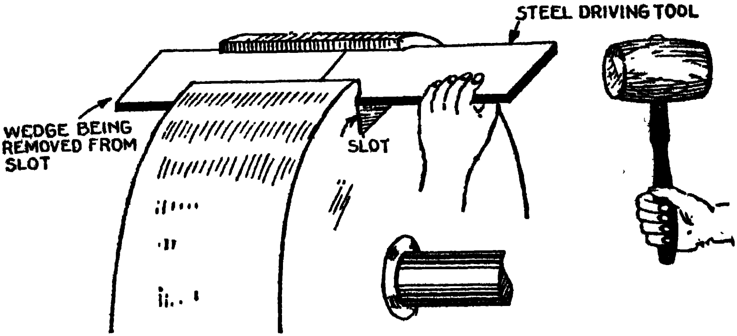
Sundry data as to whether multiplex; connection of equalizer rings if any, and such unusual items.

NOTE.—A "coil" may be defined as the wire or turns from one commutator bar to the bar connected to its other end.

NOTE.—A "bundle" is a number of single coils grouped together in a slot.

Dismantling.—When an armature is brought into the shop to be rewound, it must first be stripped of the old winding and re-insulated throughout. Before doing this the winding should be examined and a complete winding data sheet made out as outlined in the preceding section so that in rewinding, the workman will know what size wire to use, number of turns per slot, pitch of coil and the numerous other items necessary to duplicate the former winding.

In dismantling, the first operation is to remove the banding wires, being careful if these be cut with a chisel not to dent the teeth.



FIGS. 589 and 590.—Operation of removing wedge from slot of armature by use of steel driving tool.

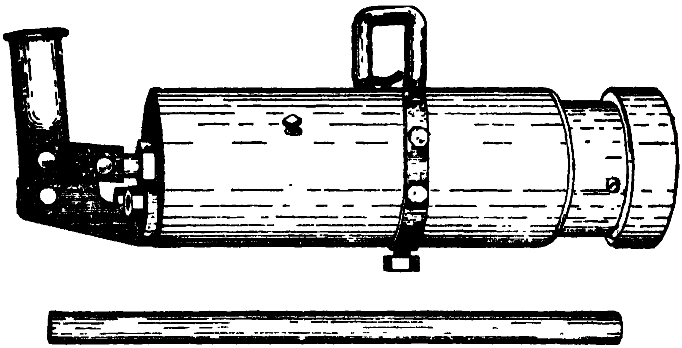
Next, unsolder the commutator leads and remove slot wedges with a steel drive of the same size as the wedge. Now remove coils by raising the top sides for a distance of the throw, when the bottom side of each coil can be reached and the others taken out.

Take out one coil as carefully as possible without disturbing its shape so that it will serve as a guide in forming the new coils.

After all coils have been removed, the slots should be cleaned of the old insulation, by burning with a torch and any burrs or rough places smoothed with a file.

Repairing the Commutator.—Whether new or old, commutators should be tested for grounds and short circuits, and repaired if necessary.

If necessary to replace the mica, use only soft amber mica or plate for the segments, never use any kind of paper fibre or moulded compositions. If hard mica be used between the segments it will usually result in high mica, and consequent bad sparking when the machine has run a while, if not under cut. Under cutting is to be avoided on high voltage machines where possible, but must be done on low voltage machines and machines using graphite brushes.



FIGS. 591 and 592.—Peerless portable hydraulic pinion puller for removing pinions from armature shafts. The machine is used in connection with special cast steel split jaws which clamp over the pinion, pulling in a straight line, and therefore can be applied to the armature without removing the latter from the motor, it being unnecessary to either block up the puller or the motor. Capacity ample to remove pinions of any size used in electric railway service; a few strokes on the operating lever will remove the most obstinate pinion, and as a light oil is used as the hydraulic medium, there is no danger of freezing.

The best thickness for segment mica and ordinary voltage machines such as 110 to 550 voltage is .032″. It almost seems strange that a reduction to .025 will result in about four times as many break downs. An increase to say .040″ will result in high mica and accompanying sparking troubles. On low voltage machines thinner mica is successfully employed.

The clamping toes and foot of the mica must be thinned down a few thousandths of an inch as shown in fig. 606 to allow for giving of the copper segments, otherwise the inside of the commutator will be tight and the outside loose.

For the clamping rings, sleeves, etc., use only a hard India mica, as

amber mica is too soft, and will crush when enough strain is applied to make good commutation.

If the insulation be burnt away, but can be thoroughly cleaned out so as to present a perfectly new surface of mica, the hole may be plugged with some of the commutator repairing compounds, a number of which are now on the market, some of which will stand up better than the original mica.

Riveted commutators can be opened up by grinding a lathe tool to a very fine point, with the sides at an angle of about 15° and turning or "sticking" the upset or burr off the sleeve. This will leave the sleeve the

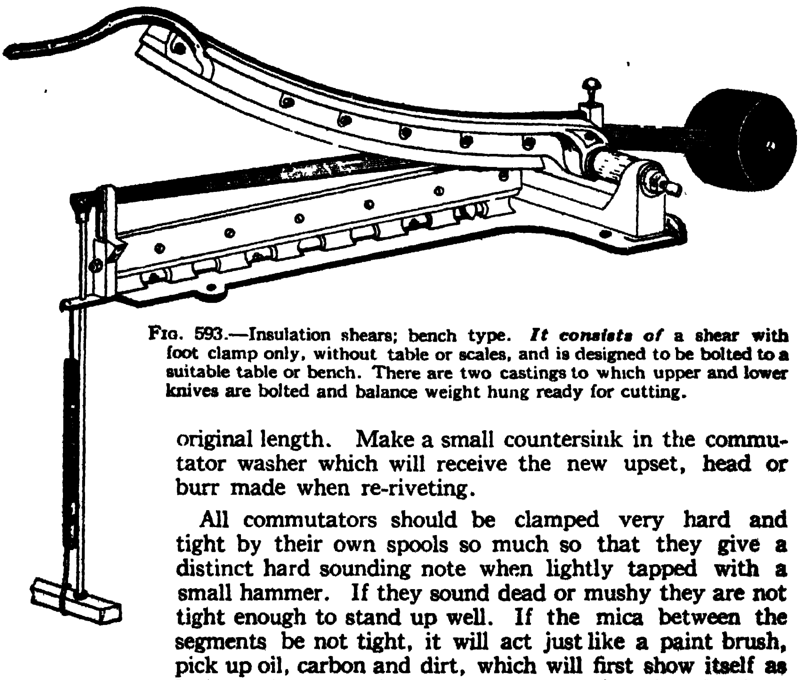


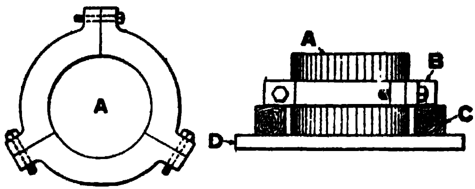
FIG. 593.—Insulation shears; bench type. *It consists of* a shear with foot clamp only, without table or scales, and is designed to be bolted to a suitable table or bench. There are two castings to which upper and lower knives are bolted and balance weight hung ready for cutting.

original length. Make a small countersink in the commutator washer which will receive the new upset, head or burr made when re-riveting.

All commutators should be clamped very hard and tight by their own spools so much so that they give a distinct hard sounding note when lightly tapped with a small hammer. If they sound dead or mushy they are not tight enough to stand up well. If the mica between the segments be not tight, it will act just like a paint brush, pick up oil, carbon and dirt, which will first show itself as bright white flashes going around the commutator. Occasionally these flashes are spectacular, but do little damage beyond wasting energy; they are, however, succeeded by dull red fire like that on the end of a cigar, which does the real damage of short circuiting the commutator, finally burning out the armature. It is therefore important that commutators be tight.

Where built up mica is used commutators should be baked at a temperature high enough to melt shellac, from 2 to 4 hours and very large ones longer and tightened two or three times during this process of baking, they should be tightened *hot*.

In the repair shop it sometimes helps to turn the flame of a torch through the sleeve or inside of the commutator getting it hot while the segments remain cold, and tightening it up very firmly whereupon the contraction of the sleeve will lend its aid.



FIGS. 594 and 595.—Ring or clamp for holding commutator bars together when assembling and method of using. The clamp should be slightly smaller than the diameter of the commutator. *In using*, wooden blocks C, may be used as distance pieces to align the clamp at the middle of the commutator. D, is an iron face plate. The distance pieces C, and clamp B, are placed on the plate D, as shown, and the bars and mica segments stacked in a circular form within it. Be careful not to omit any of the mica segments, so that each bar is insulated. Carefully count the bars to be sure that the correct number are in position. Take several pieces of copper wire (about No. 9 B. & S. gauge) and remove the insulation. Place these around the commutator near the top and lower ends to act as band wires, and twist them tight. The clamp may then be removed, and the commutator straightened. Bring out the mica segments even with the surface of the bars by holding the fingers against the inside edge of the segments and tapping the bars on the outside with a small mallet. Place a square or steel scale on the face plate, examine and see that the bars line up perpendicularly with one edge of the square. If they do not, a gentle pressure one way or the other on the top end of the commutator with the palm of the hand will bring them in line. See that each bar and segment is down flat against the surface of the plate, since that end will be fastened to the face plate on the lathe facing off the ends of the bars. Tap each bar and segment down solid with a square ended punch, a little narrower than the thickness of the bar. When this has been done, the band wires can be drawn a little tighter and the surface of the commutator, where the clamp will fit, should be filed to remove any protruding mica, and present a smooth surface for the clamp. Replace each section of the clamp about the commutator again using the wooden blocks mentioned before. Draw the clamp tight, being sure to leave the same amount of space between each clamp section. A small gas burner, or some other source of heat should be handy, and the commutator placed over it and heated. When it is good and hot to the hand, tighten the clamp, allow it to cool, and again tighten. Flame should not play on the commutator continuously.

Commutators held together by the present day insulating compositions unless the trouble is very minor are irreparable. At the present time no insulation has been found to stand up on commutators as well as mica, which as stated above should be tightly clamped.

Truing of Commutators.—When a new or reassembled armature has been in use some time, the shrinkage of the insulation may cause commutator bars to settle resulting in an uneven

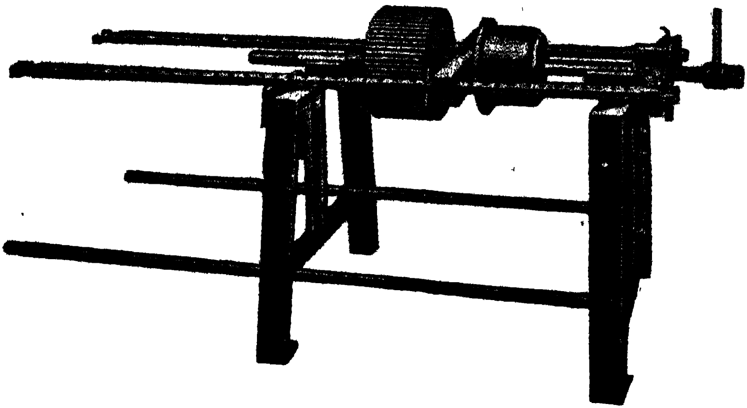
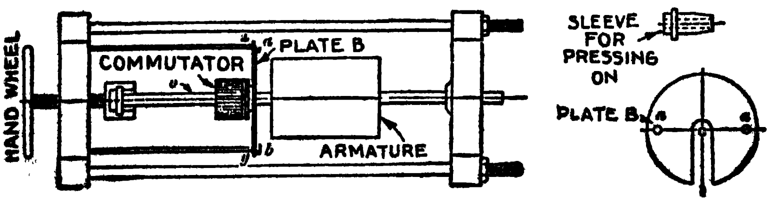


FIG. 596.—Peerless commutator press. *This tool* is hand operated and is suitable for p on or pushing off commutators, armature cores, pulleys, gears, etc. It has a capacity of 15 tons, operated by one man.



FIGS. 597 to 599.—Press for forcing on and removing a commutator. Small commutators are pressed on to the shaft by a hand press. All of the larger commutators are pressed on by means of a power press. In the above figure is shown a hand press. The plate B, is used in removing old commutators. It is placed back of the commutator as at *x,y*, with the slot C, over the shaft. Bolts *a,b*, are passed through the holes in the plate and secured by nuts. The commutator can then be forced off the shaft. In pressing on a commutator, a sleeve is placed over the shaft at O, and against the commutator. The rear end of the shaft is secured so it will withstand the pressure, and the commutator is forced on. The power presses are built on the principle of a hydraulic press. In pressing on a commutator a piece of babbit metal or soft brass should be used against the end of the shaft. The shaft should be painted with white lead before having the commutator pressed on, in order to lubricate the shaft so that the commutator will press on easily. The wiper rings are pressed on after the commutator and then the armature is ready to be connected.

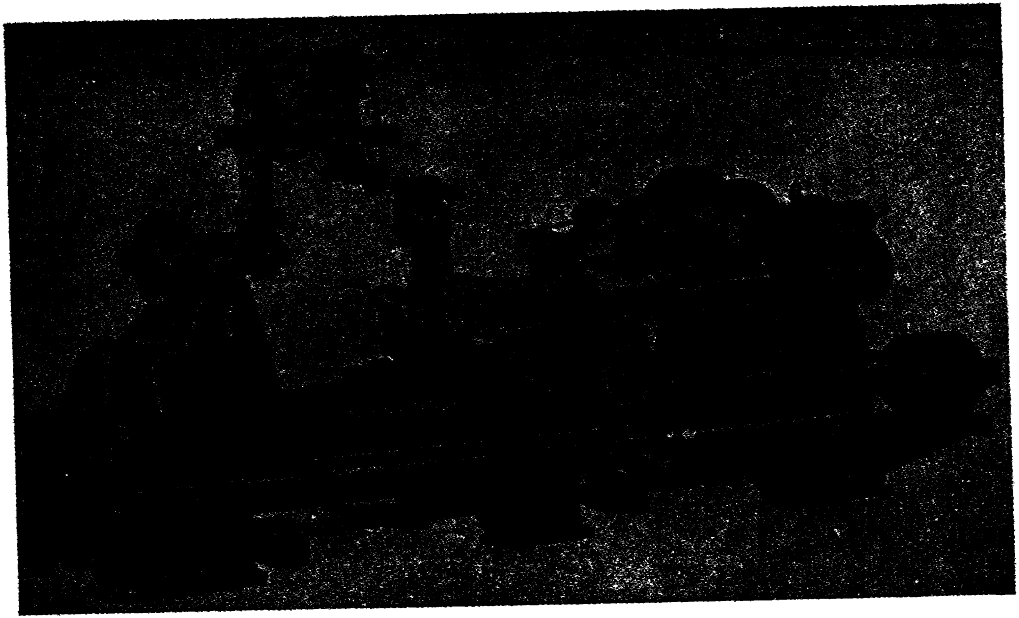


FIG. 600.—Peerless universal heavy duty armature machine showing some of its various features. This machine has the following features: 1, *banding machine* with self contained tension carriage for the band wire with ability to handle large and small armatures or stators used in railway, locomotive or stationary motors; 2, *commutator slotting device* with independent motor provided and automatic feed in both directions; 3, *commutator grinding device* with independent motor provided; 4, *commutator cutting or truing attachment* with automatic feed in both directions; 5, *field and armature coil plate* suitable for all classes of heavy form coil winding.

surface. This must be trued up by turning in a lathe when in very bad condition, but otherwise a grinding tool, or simply an application of medium sand paper No. 1 or 1½ will do.

Pressure on the sand paper may be applied with a flat stick, or

FIG. 601.—Application of Cass commutator smoothing stone. *These stones consist of* compounded abrasive material for grinding out scores or roughened and flat surfaces on commutators. Their application is extremely simple. With the machine in full operation the smoothing stone is held against the revolving commutator and moved very slowly from side to side. A coarse texture should first be used when truing the commutator, after which a stone of finer texture should be applied to secure the desired finish. With the surface true and smooth the occasional application of the finer texture stone will keep the commutator in excellent condition.

brush, utilizing the brush tension to press the paper against the commutator, but on larger machines the brushes should be lifted to prevent the dust becoming imbedded in the brush contact surface, which tends to cause poor commutation.

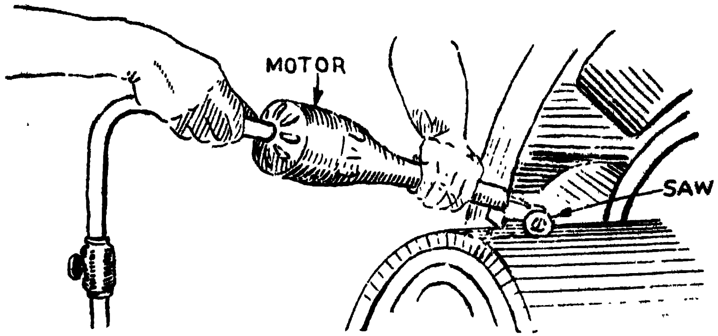


FIG. 602.—Rotary hand tool for undercutting mica and method of using. The saw is mounted between two handles and adjustable shoes are provided on each side so that the depth of the slot may be gauged and kept uniform. The saw may be driven by a small stationary motor through a flexible shaft or by a compressed air drill. In this case the armature is simply placed on a pair of V supports and clamped to prevent it turning if necessary.

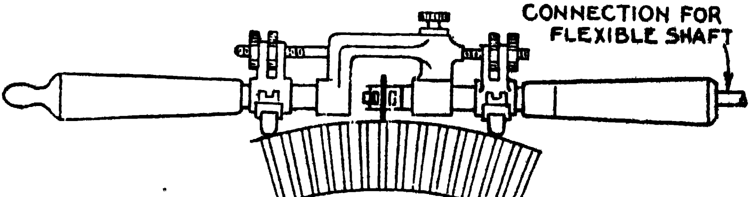


FIG. 603.—Motor driven mica cutting tool in which the cutting tool is mounted on a slide and moved back and forth by hand The drive is through a flexible shaft as shown, or a belt may be used.

High Mica.—This condition obtains after some wear if mica be too hard or brushes too soft and results in heating and burning of the commutator bars due to arcing.

In severe cases the solder melts resulting in open circuits due to leads becoming disconnected. To remedy this condition the mica must be under cut

Under Cutting of Mica.—The mica insulation between the commutator bars should be under cut from 1/32 to 1/16 in. below the surface of the bars, when necessary.

In doing this be careful to avoid leaving thin slivers of mica

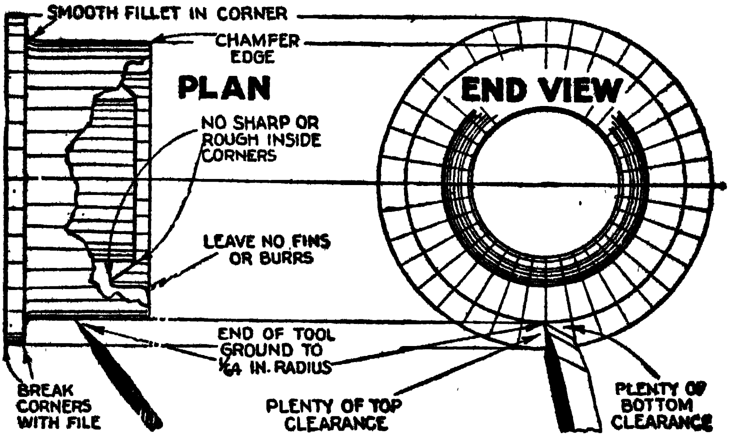


FIG. 604.—Correct setting and shape for commutator turning tool. All commutator surfaces *must* be smooth. If the tool be ground to a long radius point so common in turning steel and with a flat top clearance so proper for brass work, the speed of production on the job will run down about 5 to 1, a job that should take ten minutes with a properly ground tool, will take an hour and even 1½ hours, the speed of turning will be much slower, and the chattering will be very severe, necessitating the use of a steady rest on many armatures that otherwise would not require it. Whereas if the tool be ground as here shown with the two bevels on the side very sharp say about 30°, with plenty of bottom clearance, and lots of top clearance, in fact the cutting edge should almost rise into a hook, and the radius of the point not to exceed 1/64" set at an angle of about 30° pointing forward in the direction of feed, the commutator can be run at high speed, and only in severe cases will a steady rest be necessary, the job will be smooth, free from burrs, will require little or no sand paper, it will only require running a few hours before the commutator sing is nearly eliminated, it will not start off with high mica. With improperly ground cutting tool, short circuits are quite prevalent.

NOTE.—*In turning commutators* whether inside or outside, internal or external angles, all angles should be well rounded, this particularly applies to the outside corner which should be turned to a radius of about ⅛" a little more or less according to the size of the commutator. The reason for this is, that if the outside corner of the commutator be sharp, short circuits will start at this point about four times as often as at any other part of the commutator even including the brush path. The principal reason for rounding the rest of the corners internal and external and seeing that they are smooth, is about the same, but in addition to this if the corners be not made smooth, and round, there seems to be a strong tendency for break downs to occur, and to drag chips, dirt, etc. across the rough places.

next to the bars. Special motor driven saws are available for cutting the mica. Small commutators may be machine cut on a milling machine. Various hand tools also have been devised for cutting the mica.

High and Low Commutator Bars.—When a commutator is hot the shellac in the mica being in a soft state will allow the bars to move more or less under centrifugal force due to rotation which is frequently the cause of high or low bars.

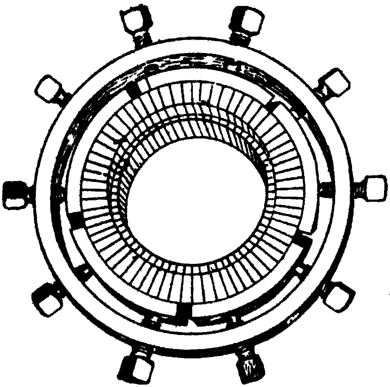
FIGS. 605 and 606.—Mica segment F, cut from sheet using bar L, as pattern. Such a segment is cut large at top and at ends so as to turn down evenly with copper bars when commutator is finally surfaced. Clamping toes and foot must be thinned to allow for give of copper bars and to obtain tight clamping of mica on the outside of commutator. Make toes .003 to .004 ins. thinner; lower edge .002 thinner.

To remedy this defect let machine run till hot, then take up on commutator ring, repeating the process several times if necessary. High or low bars can sometimes be re-aligned by respectively tapping down, or prying up and inserting underneath a narrow strip of mica.

Burn Outs.—The trouble which occurs between commutator bars is usually due to loosely clamped mica which collects oil and dust, causing leakage of current from bar to bar with resulting carbonizing of the mica and finally a short circuit.

NOTE.—*Commutator Slotting.* For slotting, a home made outfit is frequently used. A good cutting tool consists of a circular saw or miller ¾ to 1¼ in. in diameter with from 15 to 30 teeth. The thickness of the saw should be slightly greater than that of the mica, that is for mica .03 in. thick a .035 in. saw should be used. In this way the mica can be removed completely with no thin layers left at the sides. This saw may be easily mounted on the tool carriage of a lathe, and driven at from 1,200 to 1,800 *r.p.m.* by a belt from the line shaft or by a small motor mounted on the carriage. With a spacer of the same width as the commutator bars two saws may be used and the slotting operation be performed in half the time. Instead of the circular saw, a lathe tool ground to fit the slots may be used by mounting it in the tool post and moving back and forth across the commutator by operating the carriage. It may also be mounted on a special stationary post and moved back and forth by a hand lever. These methods require a lathe which is not always available, and several types of machines avoiding this are in use.

Plugging.—When the mica is not burned too deep, clean out the hole thoroughly and plug with a filling made of some good plugging compound, such as *plus mica;* there are several good compounds on the market.



In emergency when these are not available a compound mica of plaster of paris, one part powdered mica and enough glue to make a thick paste may be used, but this is not a good compound as the plaster of paris is a sulphate which attacks copper.

Dismantling Commutator for Repairs.—If a burned commutator bar or mica strip is to be removed for repairs, loosen clamping ring bolts and mark ring so that it can be replaced in the same position.

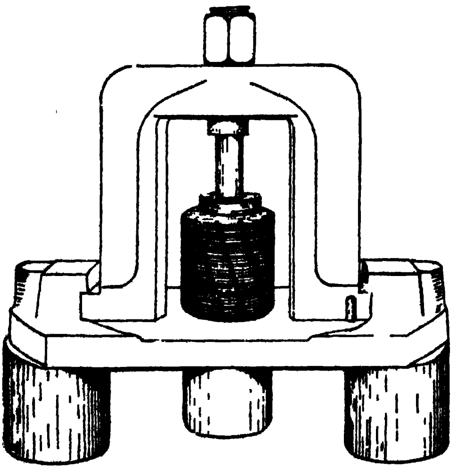
FIG. 607.—Commutator clamp. *It consists of* an outer steel ring having a number of radial tappings for set screws. These set screws bear against an inner ring split into a number of sections. *In making a commutator,* the segments and mica strips are inserted through the inner ring and the screws tightened so that the segments are firmly joined together. V grooves are then turned therein and clamping rings of corresponding shape are fitted. These are bolted on and the clamp removed, the segments now being retained in position by the rings. The ends of inner ring segments should be skewed.

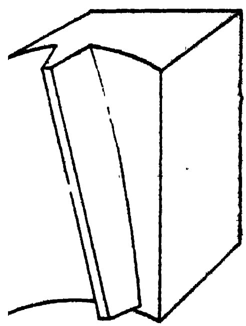
Remove clamping ring and if the mica be stuck to commutator it should be carefully pried loose with a knife or thin tool. After the ring is taken off it is easy to remove any of the bars. In replacing a bar the mica segment should be put in first, being careful to first see that there is no dust or solder lodged on the back of mica ring.

Tightening a Repaired Commutator.—When assembled put on clamp ring and screw up bolts. Bake in oven to drive out the shellac, let cool and again take up on ring bolts.

Repeat operation one or more times until there is no slack in the bolts.

Insulating the Cores.—The heads of small bipolar and most multipolar armatures should have fibre punchings on them. If on repair jobs these heads have been destroyed, a fair substitute may be made by cutting fibre washers $\frac{1}{32}$ to $\frac{1}{16}''$ thick about $\frac{1}{32}$ to $\frac{1}{16}''$ larger than the bottom diameter of the slots allowing the slot insulation to rest on the same.





FIGS. 608 and 609.—Jig and block for building up laminated core with skewed slots. The jig has a concave block fitted with a key which gives uniform skewing as the laminations are slipped on the shaft. The object of skewing is to reduce the *magnetic hum*. However, it also reduces the output of the machine from 15 to 20%.

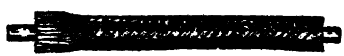


FIG. 610.—Insulating cotton sleeving used for insulating and protecting armature coil leads. It usually comes in gray, but can be obtained in red, blue or black.

Washers may be cut to cover any other bare portions of any suitable material, and should be snugly fitted over the shaft insulation that the wire may not work down between them, or the shaft insulation should be tightly fitted against the head insulation.

Never use friction tape on the shaft. It makes the heads too big, as the wire does not readily slide over such a surface. Use something that will let it slide readily, as paper, empire, fibre or glued paper used for fastening packages.

Friction tapes around a piece of electrical machinery are open to several serious objections and should not be used. Oil cuts the gums thereon, they absorb dirt and become conductors, making a nasty mess. Friction tapes have *low* dielectric strength. Most of them contain sulphur which in time corrodes through fine wires.

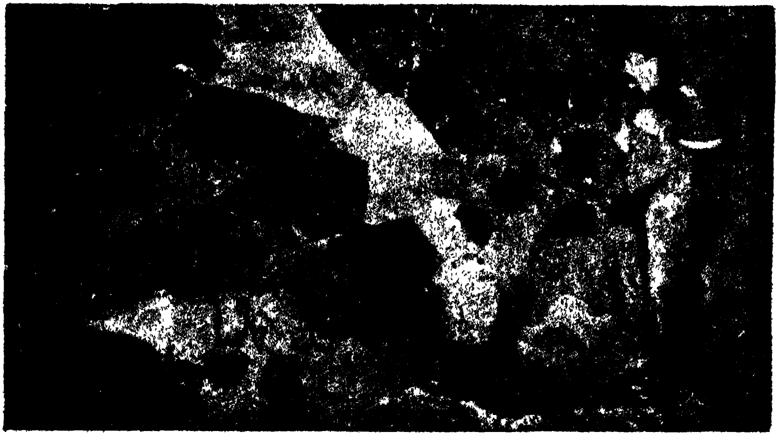


FIG. 611.—View of mica vein.

Insulation of Slots.—Probably the best of all around insulating material for armature slots is some form of tough fibrous paper which will withstand considerable rough usage and will form up pretty well. Such paper may be purchased under many names, but was originally called "Leatheroid." This material has high dielectric strength—250 to 350 volts per mil thickness.

For slots to ⅝" deep 110 volt range of insulation, wire sizes No. 28 B & S and finer, .007" or .010 paper is ample, if fibre heads be intact. If not, for

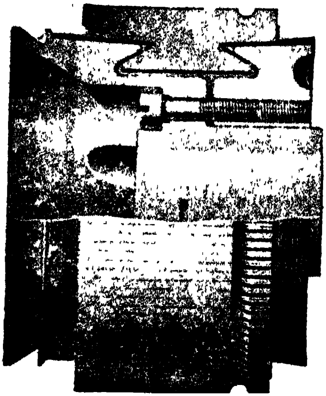


FIG. 612.—Mica Insulator Co micanite commutator rings as applied to railway motor commutator.

220 volts and for deep slots to ⅞" and heavy wires to say No. 18, increase the thickness to say .010" or .015". For higher voltages or coarse wires, more insulation is needed.

One of the best all around methods of insulating the slots, for either machine or hand winding is the continuous strip method, as shown in figs. 614 and 616. It has the advantages that the wire can never get down behind the insulation, choking the slot and grounding, is free from grounds no matter to what degree the slot may be filled.

It is not necessary to stop and adjust the insulation at starting, permitting continuous winding at high speeds without stopping for further adjustment of the insulation; permits of any kind of winding, tight or loose being applied, and is itself easy to apply. If done per directions, requires no pasting, sticking or gluing, few tools, and also allows the ends of the insulation to be "tucked" saving the cost of armature sticks, and what is very important, prevents the sharp edge of the tooth injuring the wire.

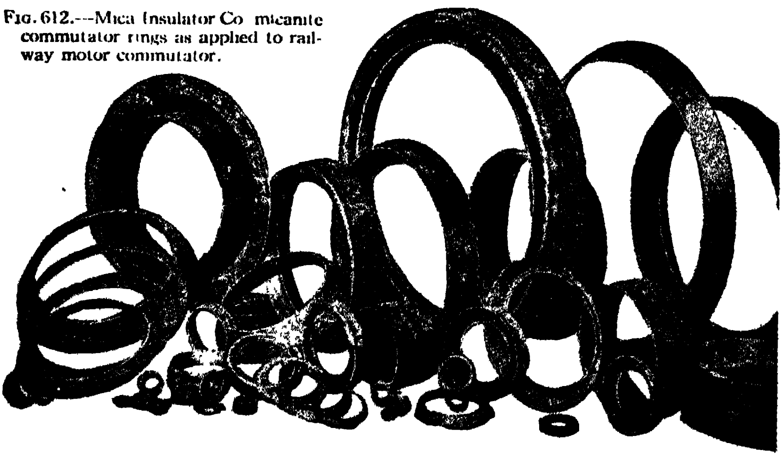
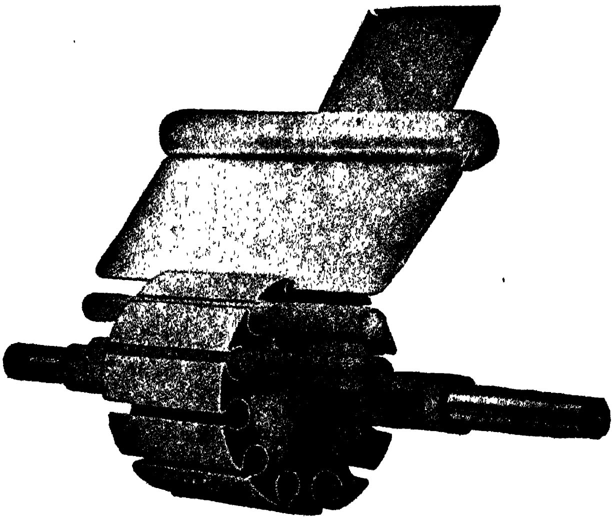


FIG. 613.—Mica Insulator Co. micanite commutator rings, various sizes.

Where it is desired to insulate between the top and bottom coils, this



FIGS 614.—Method of insulating armatures. Cut a long strip lengthwise of the grain as this gives the greatest resistance to tearing at the edge by the tension of the wire a little wider than the length of the armature to be insulated. (For twisted slots much wider.) Insert the first end of the paper into a slot far enough to cover about ¾ of the slot, slip in a peg just fitting the slot, which will shape the paper as shown in figs. 614 and 616. Pull tight over the corner of the slot, rub paper with a drift tool where it emerges from the slot on both sides in a manner to give it a slight crease at this point; insert the insulation in the next slot, which is best done by "blistering" the insulation slightly over the tooth which is just to be covered, pressing it into the slot with a drift tool such as shown in the figure, the edges of which are rounded, the "blistering" allowing a little slack on the fixed end of the insulation for this purpose. Before pressing the tool to the bottom of the slot, hold the long end of the paper against the back of the tool, and press downwardly and angularly toward the slot which has just been insulated, in a manner to crease the insulation over the edge of the slot. After forming this crease as described, release the long end of the insulation, press it downward into the slot, when it will be found to curl around and more or less fit the slot. The drift tool having been removed, a pin may be inserted. When the second pin has been removed, a pin may be used again, etc. Two pins are all that are necessary. Some use only one. When the first slot is reached again, cut the insulation long enough to reach down into the slot and lap well over the first end, and the armature is ready for winding.

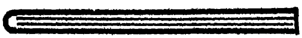


FIG. 615.—Peg for forming and anchoring insulation in slots while applying insulation.

same continuous strip method may be used to advantage, by simply using a smaller and appropriately shaped peg. It should be noted, in making these pegs, that the first coils usually lay in the slot diagonally, and that the shape of the peg should therefore approximate the slope of the first coil. Either empire or leatheroid may be used for separator. Where it is desired to use more insulation between coils, strips may be cut which exactly match the width of the slot, and be driven home on top of the coil in a manner to compress the coil and wedge into the slots.

It is better not to attempt to use two thicknesses of insulating material for increased dielectric strength, but to increase the thickness of the insulation as the thinner insulations tear more readily at least in deep slots.

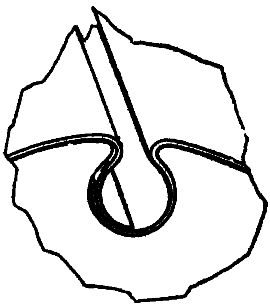


Fig. 616.—Detail of armature slot showing method of insulation.

Where it is necessary to use a layer of oiled muslin or other materials in addition to the "leatheroid" it is best to insert slot size pieces of oiled muslin under the paper.

The finer the wire with which the armature is to be wound, the more care is necessary in fitting the insulation to the slot, as fine wires are not strong enough to crowd it into place.

Where the slot insulation required is very thick or slot openings too narrow, and sometimes for other reasons it may be necessary or desirable to use cut to size insulation, as shown in fig. 617. The correct size can be easily obtained by inserting the first piece in the slot around a pin or mandrel, marking along the edges of the slot with a knife, taking out, cutting to size, and making the balance to match this sample. The grain of the paper should run around the slot, and not lengthwise, for it is obvious

that thus it will best resist tearing. Allow the insulation to stick out a little beyond the end of the core, and wing or "dog ear" the corners thereof away from the slots, as shown. With insulation cut to size and placed in round slots, it is occasionally necessary to cement the insulation in the slots, but don't use liquid glues, many of them contain acid.

Magnet Wires.—Most small armatures including fan motor, fractional horse power, universal and a few automobile dynamo armatures using wires No. 20 and finer may be and usually are

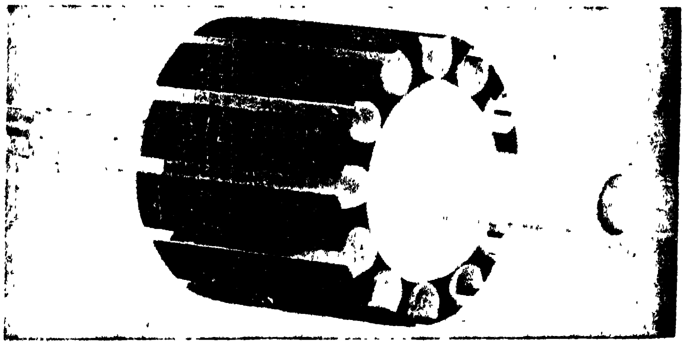


Fig. 617.—Armature insulated with thick cut insulation or common vulcanized fibre, cut to exact size of the slots.

wound random, that is not in layers. They are best wound by machine, as machine windings are more nearly parallel, take up less space, are freer from short circuits and mistakes, and are put on from six to thirty times faster.

Armatures requiring wires coarser than No. 20 B & S gauge should be wound in layers, or have insulation inserted between the coils, or wound with triple covered wires, or wound on forms and assembled with auxiliary insulation. The auxiliary insulation is required for mechanical reasons on all armatures and for dielectric reasons on higher voltage armatures as well.

Armatures of any kind and particularly where the wire is

wound directly on the cores should never be wound with anything but double or heavier covered wires if durability in use and freedom from troubles be a consideration, for the life of an armature wound with a single covered wire of any type is limited.

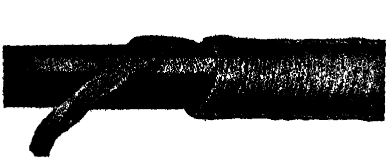
Wires which may be classed as double covered are in order of their thermo-mechanically desirable qualities for armature winding, and their range of usefulness for random windings placed directly on the armature, are about as here given.

	Types of Covering	Usual Sizes
Double covered	cotton (and an) enamel	21 to 30
	double cotton	20 to 30
	silk (and an) enamel	28 and finer
	double silk	
Triple covered	two cotton one enamel	16 to 20
	triple cotton	14 to 20
	triple silk	Not used

NOTE.—*Double cotton covered* or cotton and enamel covered wires are the best *all around wires* for winding armatures. They stand a reasonable amount of heat, stand the handling, stand up under prolonged and continuous use, work nicely, and are comparatively cheap. Hence use a double cotton or cotton and enamel covered wire for ordinary armature purposes, except where the size of the wire is pretty fine, say No. 28 and finer, and even then if the room can be spared.

NOTE.—*Silk covered wire* is delicate, and stands the least heat, burns out quickest by slow roasting, but takes little room. Silk covered wires are highly useful where a large number of turns are required of fine size, and when cotton would require an excessive volume in the slots. Either silk or silk enamel should be avoided for armature work on those sizes coarser than about No. 27 or No. 28 gauge. Above this size they are very delicate, require to be carefully insulated between coils and sometimes between layers, and, if the armature be small, they will frequently take up more room in the slots than double cotton wire if the latter be machine wound.

NOTE.—*Wires with single insulation* are only suitable for magnet and field coils, and even these are not suitable when the size of the wire is considerable, as for instance, No. 12 and coarser.



Figs. 618 and 619.—American Steel & Wire Co. single and double cotton covered magnet wire. Fig. 618, single covered; fig. 619, double covered.

Properties of Round Cotton Covered Magnet Wire

American Wire Gauge (B & S.)	Diameter Inches	Allowable Variation Either Way in Per Cent	Rated Area in Cir. Mils	Single Cotton-covered Approximate Values		Double Cotton-covered Approximate Values	
				Outside Diameter Inches	Approximate Pounds per 1000 Feet	Outside Diameter Inches	Approximate Pounds per 1000 Feet
0	0.3249	½ of 1	105,625	.333	321	.339	323
1	.2893	½ of 1	83,694	.297	255	.303	256
2	.2576	½ of 1	66,358	.266	202	.272	203
3	.2294	¾ of 1	52,624	.237	160	.243	161
4	.2043	¾ of 1	41,738	.212	127	.218	128
5	.1819	¾ of 1	33,088	.190	101	.196	102
6	.1620	¾ of 1	26,244	.170	80	.176	81
7	.1443	¾ of 1	20,822	.152	64	.158	64
8	.1285	1	16,512	.137	50.4	.142	51
9	.1144	1	13,087	.120	40.1	.125	40.4
10	.1019	1	10,384	.108	31.8	.113	32.1
11	.0907	1	8,226	.097	25.3	.102	25.5
12	.0808	1¼	6,528	.087	20	.092	20.3
13	.0720	1¼	5,184	.078	16	.083	16.2
14	.0641	1¼	4,108	.070	12.6	.075	12.9
15	.0571	1½	3,260	.063	10.1	.068	10.3
16	.0508	1½	2,580	.0553	7.96	.0598	8.13
17	.0453	1½	2,052	.0498	6.35	.0543	6.49
18	.0403	1½	1,624	.0448	5.04	.0493	5.16
19	.0359	1½	1,288	.0404	4.01	.0449	4.12
20	0.0320	1¾	1,024	0.0365	3.20	.0410	3.30
21	.0285	1¾	812.2	.0330	2.55	.0375	2.64
22	.0253	1¾	640.0	.0298	2.02	.0343	2.10
23	.0226	2	510.7	.0271	1.62	.0316	1.69
24	.0201	2	404.0	.0246	1.29	.0291	1.36
25	.0179	2	320.4	.0224	1.03	.0269	1.10
26	.0159	2	252.8	.0204	.82	.0249	.883
27	.0142	2	201.6	.0187	.66	.0232	.718
28	.0126	2	158.7	.0171	.524	.0216	.580
29	.0113	2	127.6	.0158	.427	.0203	.477
30	.0100	2½	100.0	.0140	.336	.0185	.382
31	.0089	3	79.74	.0129	.272	.0174	.316
32	.0080	3	63.20	.0120	.220	.0165	.260
33	.0071	3	50.13	.0111	.178	.0156	.216
34	.0063	3½	39.69	.0103	.144	.0148	.179
35	.0056	4	31.47	.0096	.119	.0141	.150
36	.0050	4½	25	.0090	.099	.0135	.127

Fine Sizes Silk Covered Round Magnet Wire

American Wire Gauge (B. & S.)	Diameter Inches	Area Cir. Mils	Single Silk: Maximum Outside Diameter Inches	Single Silk: Approximate Feet per Pound	Single Silk: Approximate Pounds per 1000 Feet	Double Silk: Maximum Outside Diameter Inches	Double Silk: Approximate Feet per Pound	Double Silk: Approximate Pounds per 1000 Feet
20	.0320	1,024	.0338	316	3 14	.0356	313	3 184
21	.0285	812.2	.0303	398	2 496	.0321	393	2.533
22	.0253	640.0	.0272	502	1.97	.0290	492	2.C04
23	.0226	510.7	0244	632	1 576	.0262	623	1.606
24	.0201	404	.0219	796	1.25	.0237	781	1.277
25	.0179	320.4	.0197	1000	.994	.0215	977	1.018
26	.0159	252.8	.0177	1258	.7865	.0195	1233	.8085
27	.0142	201 6	.0160	150[illegible]	.6297	.0178	1531	.6477
28	.0126	158.7	.0144	1996	.497	.0162	1934	.514
29	.0113	127.6	.0131	2463	.4023	.0149	2380	.4162
30	.0100	100 0	.0118	3125	.3163	.0136	3003	.3294
31	.0089	79 70	.0107	3906	.2530	.0125	3731	.2661
32	.0080	63 20	.0098	4878	.2022	.0116	4651	.213
33	.0071	50 13	.0089	6060	.162	.0107	5714	.1723
34	.0063	39 69	.0081	7575	.1301	.0099	7092	.1397
35	.0056	31 47	C074	9433	.1043	.CC92	8695	.1138
36	0050	25.	0068	11627	0837	0086	10637	0930

Enameled, Single and Double Cotton Covered Enameled Magnet Wire

See American Wire Gauge (B & S)	Plain Enameled: Approx. Outside Diam. in Inches	Plain Enameled: Approx. Pounds per 1,000 Feet	Plain Enameled: Net Weight of Copper per 100 lbs. of Finished Wire	Plain Enameled: Approx. Quantity per Spool in Pounds	Enameled and Single Cotton Covered: Approx. Outside Diameter in Inches	Enameled and Single Cotton Covered: Approx. Pounds per 1,000 Feet	Enameled and Single Cotton Covered: Net Weight of Copper per 100 lbs of Finished Wire	Enameled and Single Cotton Covered: Approx. Pounds per Spool	Enameled and Double Cotton Covered: Approx. Outside Diam. in Inches	Enameled and Double Cotton Covered: Approx. Pounds per 1,000 Feet	Enameled and Double Cotton Covered: Net Weight of Copper per 100 lbs. of Finished Wire	Enameled and Double Cotton Covered: Approx. Pounds per Spool	Reel No.
16	.0533	7.92	98.5	50	.0578	8 095	96.4	50	.0623	8 265	94.4	50	460
17	.0477	6.306	98 4	50	.0522	6 461	96.0	50	.0567	6.617	93.8	50	460
18	.0426	4.997	98 3	50	.0471	5.136	95 6	50	.0516	5.272	93.1	50	460
19	.0381	3.971	98.1	13¼	.0426	4.094	95.2	13¼	.0471	4.203	92.7	13¼	443
20	.0340	3.159	98 0	13	.0385	3.270	94 7	13	.0430	3.369	91 9	13	443
21	.0305	2.510	97.9	12¾	.0350	2.613	94.0	12¾	.0395	2.705	90 8	11¾	443
22	.0271	1.978	97.8	12¼	.0316	2.009	93.5	12¼	.0361	2.155	89.8	11¼	443
23	.0243	1.580	97.7	12	.0288	1.662	92.9	12	.0333	1.738	88.8	11	443
24	.0216	1.251	97.7	11¾	.0261	1.324	92.3	11¾	.0306	1.397	87.5	10¾	443
25	.0193	.993	97.6	3½	.0238	1.060	91.4	3½	.0283	1.125	86.2	3	447
26	.0171	.782	97.7	3¼	.0216	.843	90.7	3¼	.0261	.910	84.0	2¾	447
27	.0154	.626	97.4	3¼	.0199	.680	89.7	3¼	.0244	.742	82.2	2¾	447
28	.0136	.492	97.6	3	.0181	.540	88.8	3	.0226	.597	80.5	2¾	447
29	.0123	.397	97.3	3	.0168	.441	87.6	3	.0213	.495	78.0	2½	447
30	.0109	.311	97.2	3	.0154	.351	86 3	3	.0199	.400	75.5	2½	447
31	.0097	.248	97 2	2½	.0137	.281	85.7	2½	.0187	.328	73.5	2	447
32	.0087	.197	97 1	2½	.0127	.227	84 1	2½	0172	.270	70.7	2	447
33	.0078	.157	96 9	2	.0118	.185	82 0	2	.0163	.225	67.4	1¾	447
34	.0069	.124	97.1	2	.0109	.149	80 3	2	.0154	.187	64.2	1½	447

NOTE.—*For field work,* good enameled wires stand up as good or better than wires with other single insulation, if the coils be *wound* on *spools* or *equivalent*. Winding armatures with plain enameled wires or for that matter any other single covered wire may be regarded in the same light as tight rope walking—it is done, but not recommended as approved or safe practice. To wind them there are about a dozen factors that must be right all at once; among which are, that the wire must be fed to the armature under no tension requiring a spool handling device such as Chapman's dereeler, as shown in fig. 665, page 454.

Hand Winding.—To illustrate the process of winding an armature by hand, the familiar two layer drum winding is selected.

Fig. 624 shows the appearance of a completed drum winding, from the front side of the armature. The particular drum winding here considered is for an armature having 12 slots. The winding is put on as indicated by the following table:

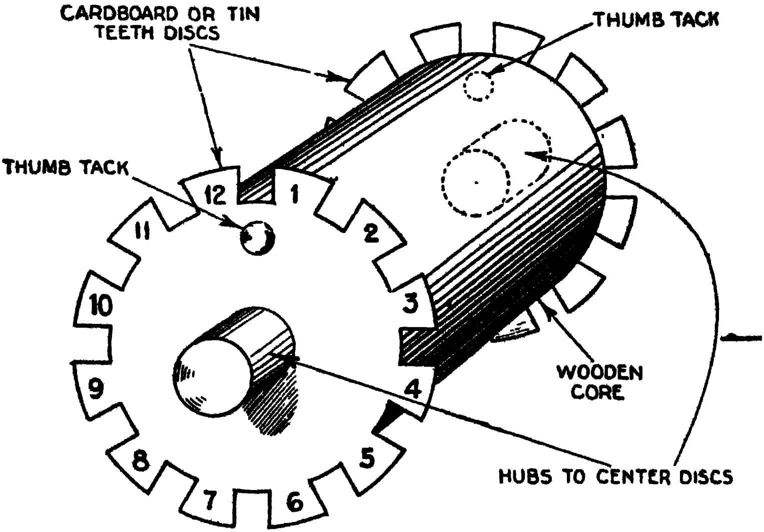


FIG. 620—Wooden armature for practice in hand winding. *It consists of* a wooden core of suitable size with a hub at each end. Heavy bristol board will answer for the discs. Cut out a number of discs, a pair each for the various numbers of slots desired. Cut hole in center of the discs same size of hub. Slip over the hubs a pair of discs having desired number of slots and secure in position with one or more thumb tacks. Use string in place of wire for practice in winding.

NOTE.—*Enameled wires*, in general, may be considered as equivalent to single covered wires. Enameled wire takes the least room, stands almost no handling, stands a good deal of heat (about 280° Fahr.) continuously and 80° more for a short while, and is useful in the small sizes for field and other work where single covered wire will suffice. The enamels should be oil and ordinary solvent proof, but seldom or never are fully so, varnishing is therefore a problem, and they must not be left in it longer than absolutely necessary. Enameled wires should stand bending without cracking be tough, and hard to scrape off.

NOTE.—*Good grades of asbestos covered wire* stand the most heat, some manufacturers claim a very high heat, even to redness. The insulation, however, is usually thicker, and comparatively delicate, for these reasons it is seldom used for armature winding.

Winding table (12 slots. Pitch 1-6)

Coil	1	2	3	4	5	6	7	8	9	10	11	12
Start in Slot	1	2	3	4	5	6	7	8	9	10	11	12
Finish in Slot	6	7	8	9	10	11	12	1	2	3	4	5

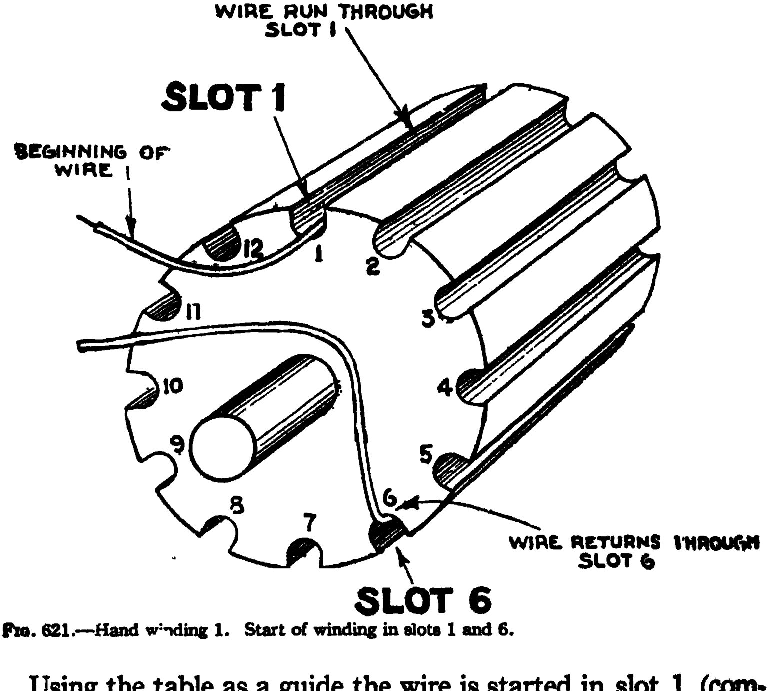


FIG. 621.—Hand winding 1. Start of winding in slots 1 and 6.

Using the table as a guide the wire is started in slot 1 (commutator end), run through slot 1, returning through slot 6, as shown in fig. 621, continuing in slots 1 and 6, till the required number of turns have been put on, ending at the starting point, that is at the beginning of slot 1, and a loop made in the wire as shown in fig. 622, long enough to reach the commutator.

After making the loop, the wire is not cut, but continued through the next pair of slots and so on according to the winding table. When all the slots are filled the beginning and ending of the winding is connected, as shown in fig. 624.

It should be noted that the bottom half of all the slots except slot No. 12 are filled when half the number of coils have been wound.

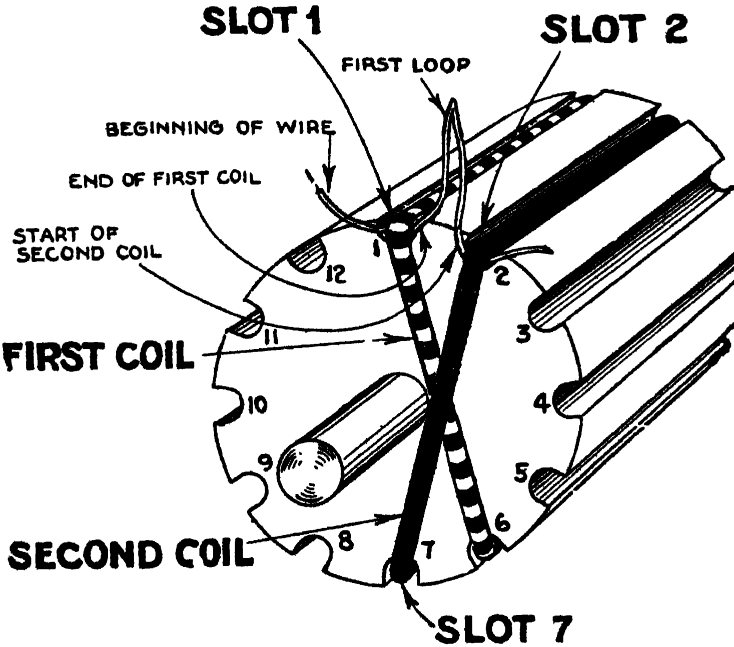


FIG. 622.—Hand winding 2. Two coils completed showing beginning of winding first loop between the first and second coil.

It should be noted that coil No. 6 which begins the upper layer, lies in both upper and lower layers. In completing the winding all the slots are again traversed by a second or upper layer (coils 7 to 12). The winding just described is for an armature having the same number of commutator bars as slots.

Now if the commutator have 24 bars (twice as many bars as slots) the winding would be put on so that there would be two loops projecting from

each slot, thus: Start as before in slot one, wind half the number of turns, make a loop, then continue to wind the remaining turns in the same slot and make a second loop. The process is repeated for the next pair of slots, continuing in accordance with the winding table till the winding is completed. Fig. 630 shows two coils wound with the double looping.

In order to avoid confusion, especially when there are more than two coils per slot, colored sleeving should be put on the loops so that they may be connected to the commutator bars in the correct sequence.

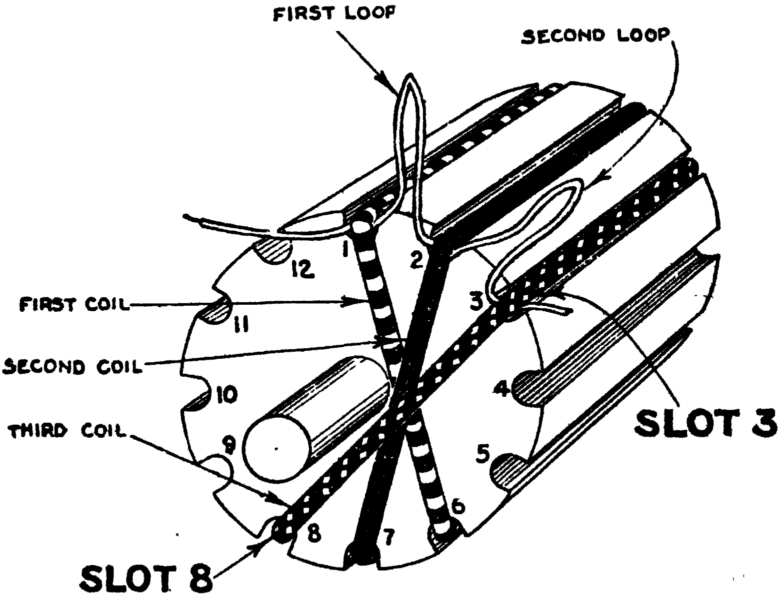


FIG. 623.—Hand winding 3. Three coils completed showing first and second loops joining them.

Armatures with commutators having two, three or more bars per slot are adapted to multi-wire winding, and facilitates hand winding as the winder takes wires from several reels and winds them simultaneously, thus, for each turn he makes, there are two. three or more turns of wire wound, depending

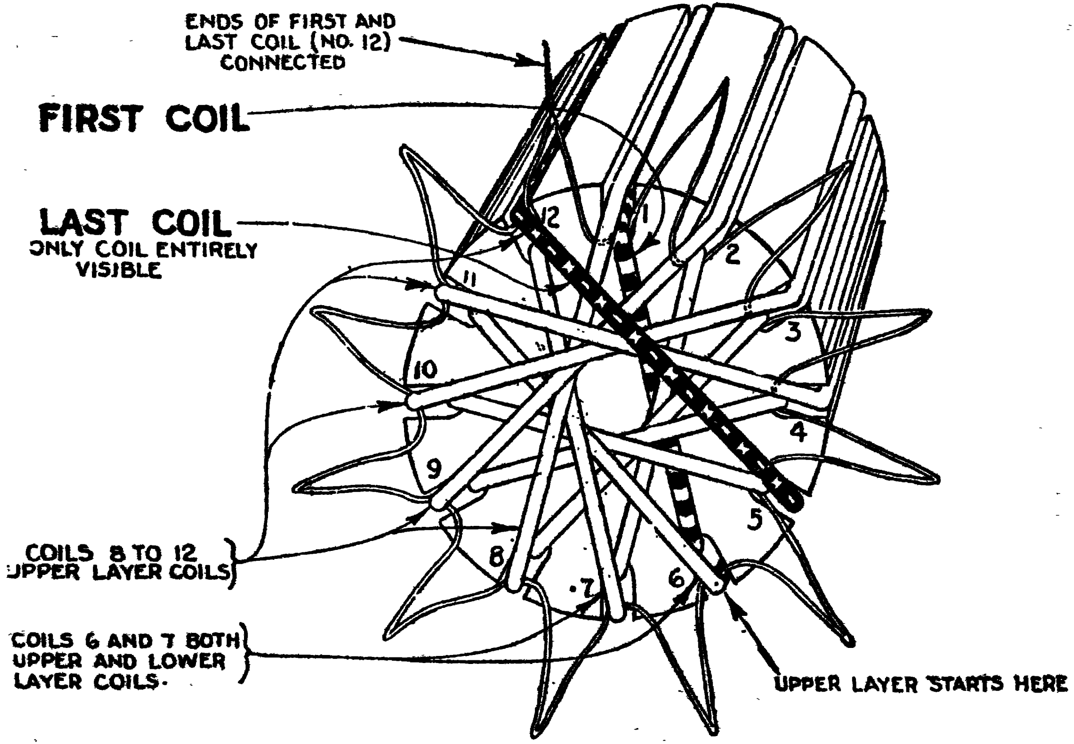


FIG. 624.—Hand winding 4. Winding complete showing last coil in position; this is the only coil entirely visible. Note that the end of this coil is joined to the first coil by twisting the wire ends. This is the two layer winding, and it will be seen from the illustration that the upper layer of coils begins with slot 6.

FIG. 625.—Partially wound barrel armature showing arrangement of coils. The core is built up of thin discs of soft annealed steel, which are slotted to allow the wire to sink below the surface, this being sometimes called *iron clad construction*. The discs are held by end plates, clamped without through bolts: The coils are machine formed of round ribbon, or bar copper depending on the size and purpose of the machine, usually without joint except at the commutator. They lie in insulated troughs, the upper layers being insulated from the lower layer by fibre.

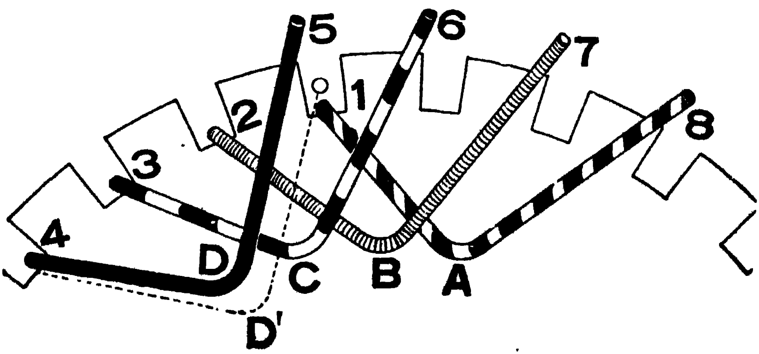


FIG. 626.—Method of placing two layer lap winding coils in armature slots. *In a two l* winding one side of a coil will be at the bottom of a slot and the other at the top of ano slot. To place coils in slot, put in the lower sides first as, 1, 2, 3, 4, of coils A, B, C, D, l ing the other side of each coil outside its slot. Evidently when enough coils to mak the inner layer have been placed this way, the upper layer side of the last coil so placed ca

FIGS. 627 and 628.—Commutator and rear ends of General Electric Standard type R.C. wave wound armature using strap coils.

Fig. 626.—*Text continued.*
put into the slot. Thus, after lower layer side 4, of coil D, is put in the slot, the upper l yer side 5, may be put in position on top of side 1, of coil A, thus moving the last coil from point D. to D', indicated by the dotted line.

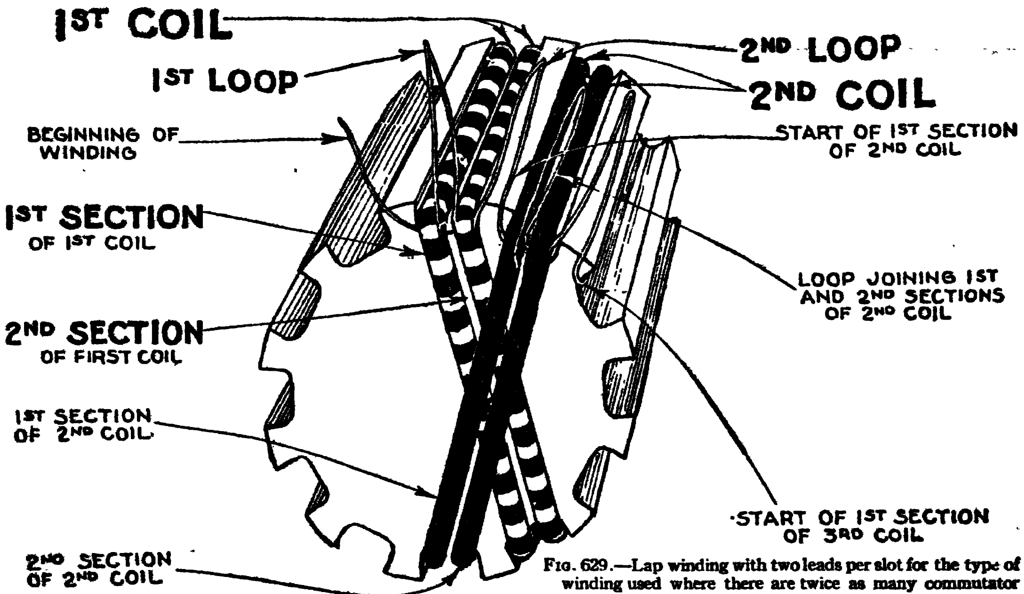


FIG. 629.—Lap winding with two leads per slot for the type of winding used where there are twice as many commutator bars as slots.

upon the number of reels in use. If there be say three commutator bars per slot three wires are wound, that is one wire for each commutator bar. Fig. 630 illustrates the process and shows the simultaneous winding of two wires called two wires in hand.

The number of wires in hand will depend on the number of times the commutator bars exceed the armature slots. Thus, for a 12 slot armature and 36 commutator bars, there will be $36 \div 12 = 3$.

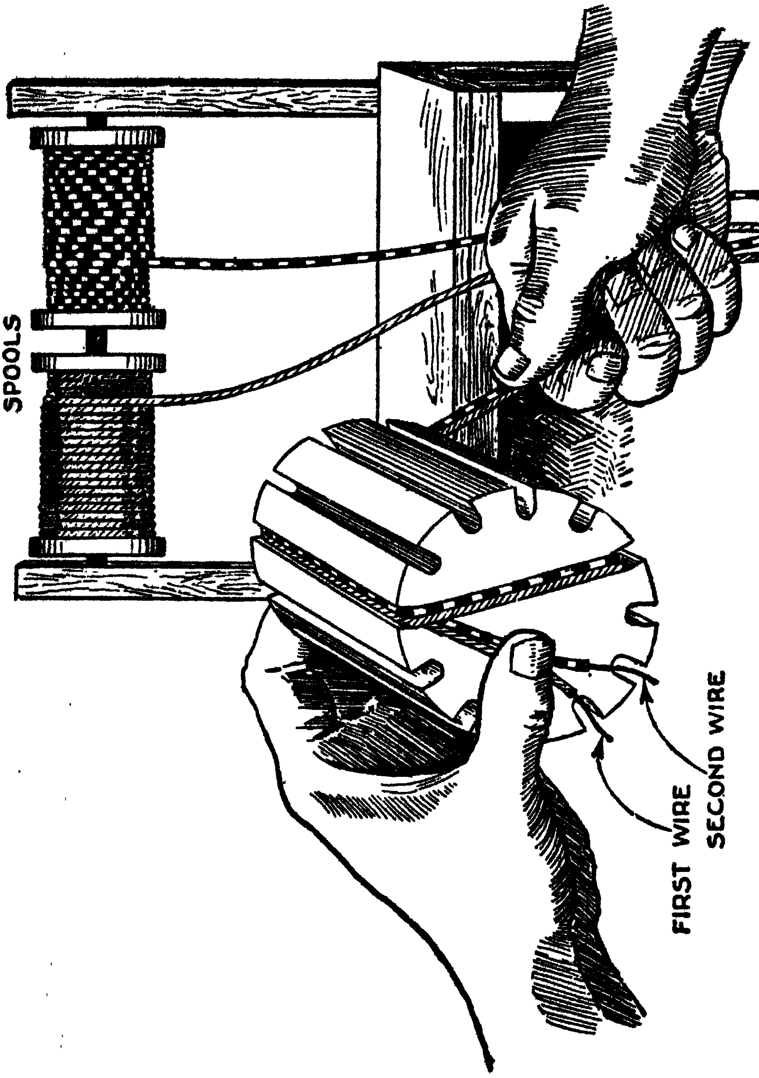
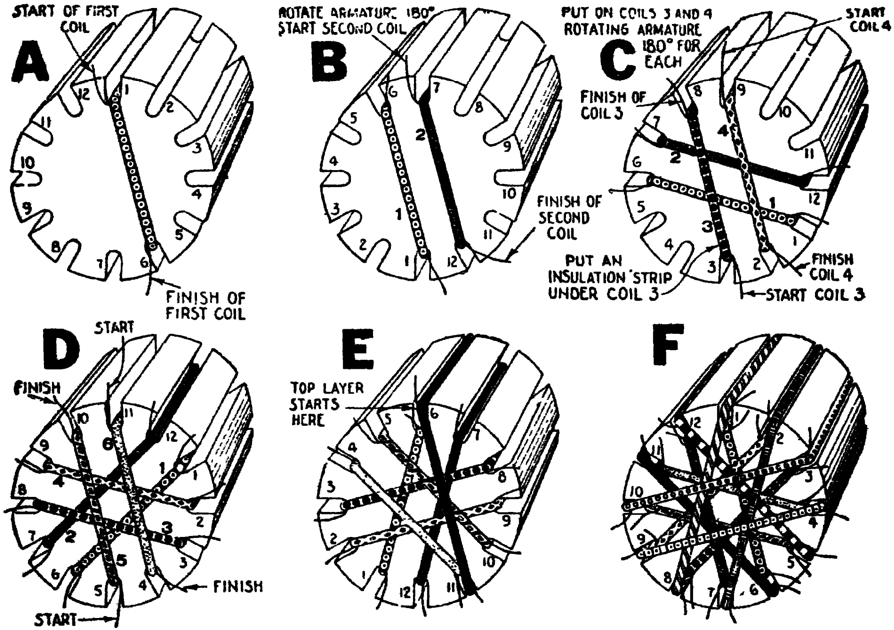
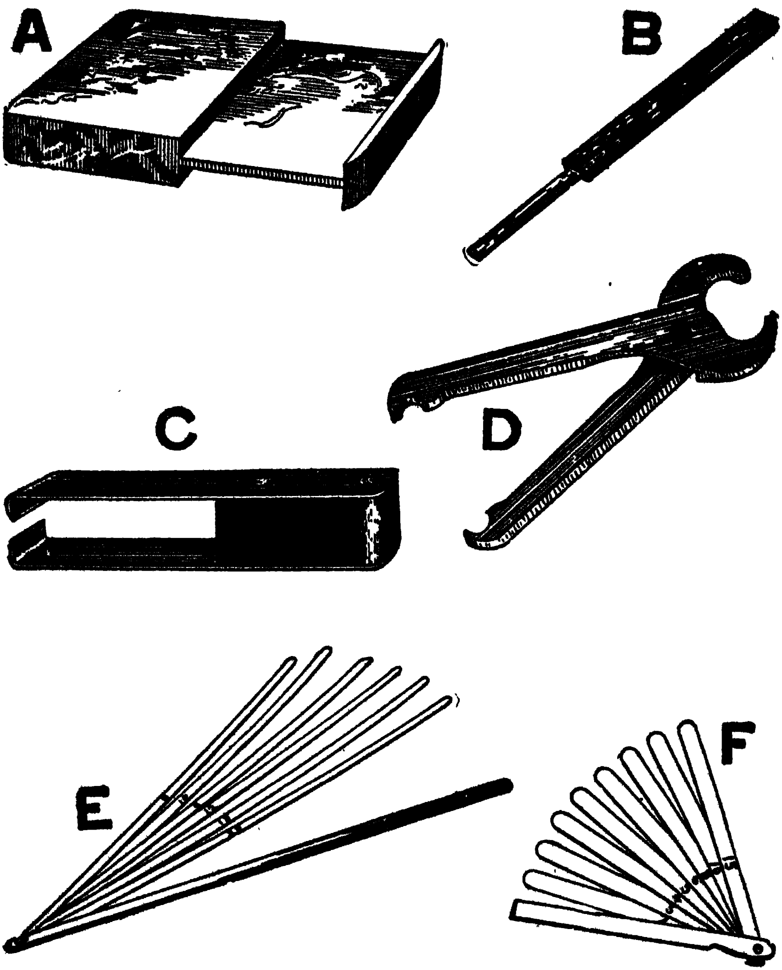


FIG. 630.—Hand winding with two wires in hand, showing the simultaneous winding of two wires.



FIGS. 631 to 636.—Operations in winding an H pattern chorded bipolar winding. A, start first coil in slot 1 and wind other side in slot 6, cutting off wire for lead long enough to reach commutator; B, rotate armature 180°, start second coil in slot 7 and wind other side in slot 12; measure lead to commutator and cut off; C, from the side of coil 2 in slot 12, skip two slots (1 and 2) and start the third coil in slot 3 and wind other side in slot 8; then turn the armature 180° and start coil 4 in slot 9 winding the other side on slot 2; D, from side of coil 4 (in slot 2) skip two slots (3 and 4) and start coil 5 in slot 5, winding the other side in slot 10; E, each slot has a coil in it now and the next coil will begin the top layer; begin the first top coil in slot 6 and wind the other side in slot 11; F, put in the other top coils using same scheme as for the bottom coils, then complete the winding.



FIGS. 637 to 642.—Armature repair tools. A, coil tamping tool; B, wedge driver; C, insulation scraper; D, fibre fuse puller pliers; E, armature air gap gauge; F, air gap and feeder gauge.

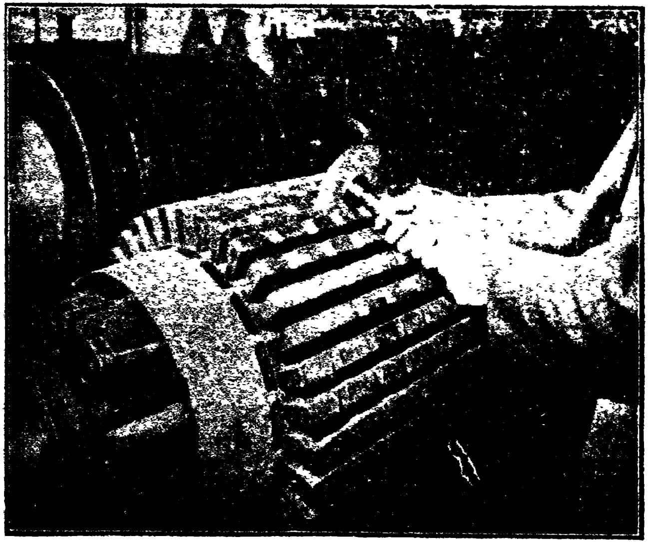
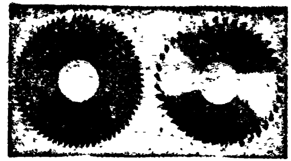
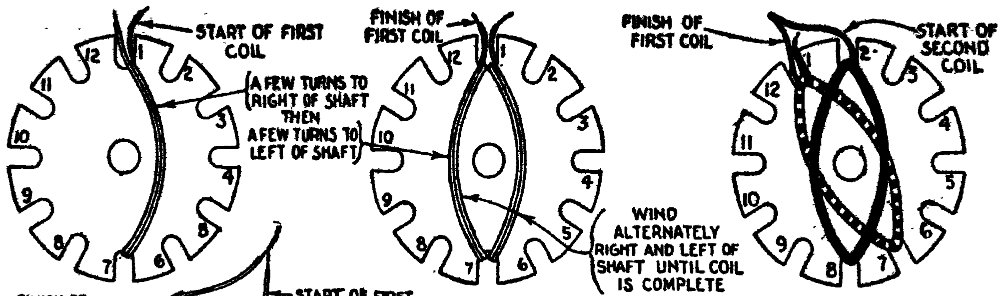


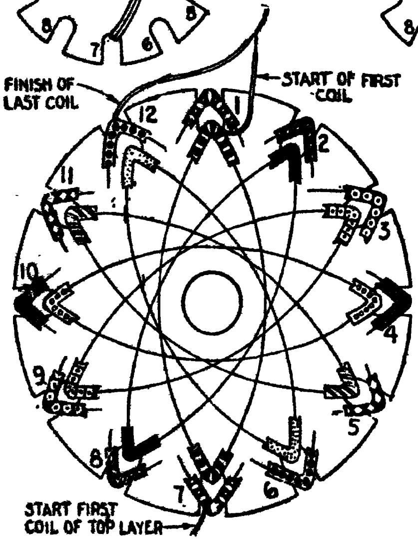
FIG. 643.—Martindale slot cleaning outfit. *It consists of* grinding disc, electrical shaft and motor drive. *It is used* to clean old insulation out of armature slots when rewinding armatures, and also to remove old solder from the riser slots.



FIGS. 645 and 646.—Saw and cutter for Aurand slotter. Fig. 645 saw; fig. 646 cutter. The cutter cuts a V-shaped slot. The angle between the cutting edges is 50° and is suitable for mica of any thickness up to .065 in.

FIG. 644.—Aurand commutator slotter. This slotter is a portable power driven machine, the essential points of which consist of a circular saw keyed to a hollow mandrel which in turn carries a worm gear. The handle contains the worm and steel driving shaft which is connected to a small universal motor. Adjustments are provided so that the machine is serviceable for commutators from 5 ins. up in diameter. The weight of the machine is borne by the adjustable depth shoe on one side and a small roller on the other. The gear reduction allows the saw to be operated at proper speed.





BOTTOM LAYER			TOP LAYER		
COIL	SLOTS		COIL	SLOTS	
1	1	7	7	7	1
2	2	8	8	8	2
3	3	9	9	9	3
4	4	10	10	10	4
5	5	11	11	11	5
6	6	12	12	12	6

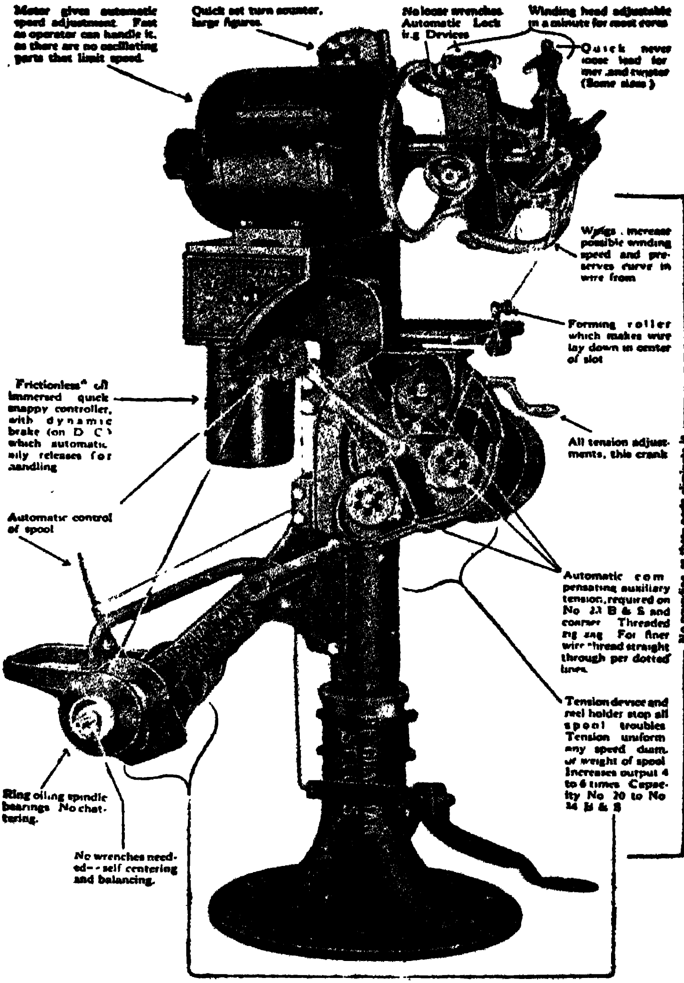


Fig. 651.—Chapman style 3 adjustable bipolar drum armature winding machine.

Machine Winding.—As practically all the fractional or smaller size bipolar armatures are wound on machines, this method of winding such armatures is here presented.

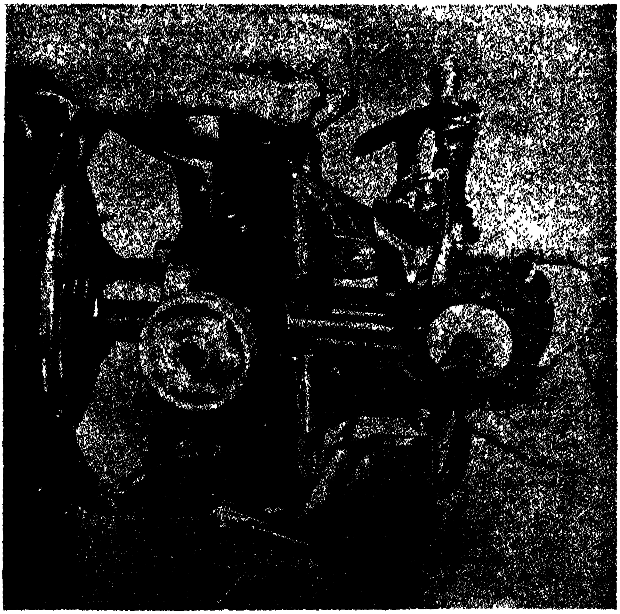


FIG. 652.—Method of placing armature in Chapman machine. Point the commutator end of the core toward you and select a pair of slots which give the correct span for the coils "spotting" them with the thumb and fingers as shown. Set the core in the jaws with their edges aligned, the jaws overhanging the slot about .003 to .010 of an in. the slots projecting. See that both sides are clear and free. Tighten up with the left hand. Let the larger part of the armature project in cord winding. (It will hold them.) The illustration shows the winding machine or head proper, equipped with 3 in. jaws, carrying the lead former and twister. When setting open slot cores, set about ⅓ of the width of the slot under the jaws, that is, allow about ⅓ of the slot to project. This is especially desirable where the core is small in diameter.

To illustrate the process of winding armatures by machine, the Chapman (style 3) adjustable bipolar drum armature winding machine, as shown in fig. 651 is here presented as an example. This machine is usually made for winding one wire at a time as

owing to the fact that when armatures are wound on such a machine with one wire at a time no subsequent sorting and pairing of the leads is necessary; this operation taking more time than it does to wind the armature.

Over 90% of the bipolar armatures wound in the United States

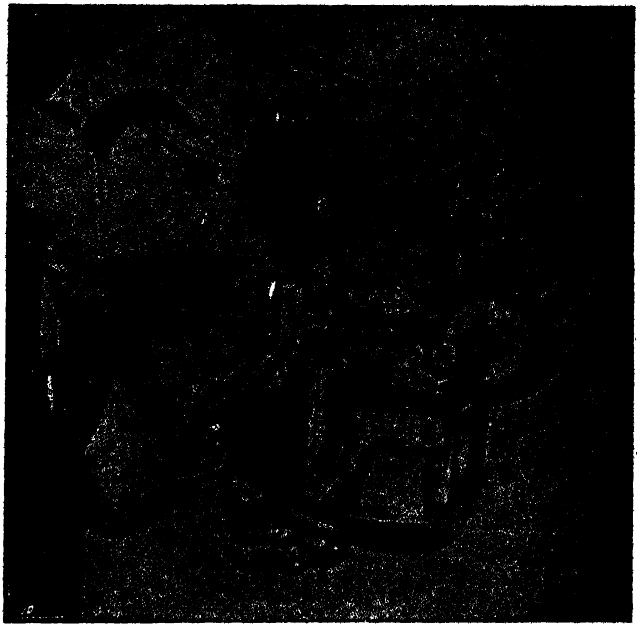


FIG. 653.—Armature placed in Chapman winding machine head. Move the depth stop against core, by turning the knob as here shown. It will both square up the armature and hold it at the proper depth. Now check the setting of the slots with the jaws, and see that the slots are clear, and that the jaws are parallel with them. After it is set correctly do not bother about the lower slot, it will hereafter take care of itself in resetting. Adjustments for paralleling are easily made, as explained in fig. 664, and accompanying directions for setting the machine to handle twisted slots; this takes about a minute.

have right hand windings thereon, and this is the type of winding that is turned out on this machine, although it is of course possible to wind left hand windings.

After the armature has been insulated as previously described it is ready for winding and is placed in the machine as shown in fig. 652. After the armature has been placed in the head, as in fig. 653 and adjustments made as directed, slip the

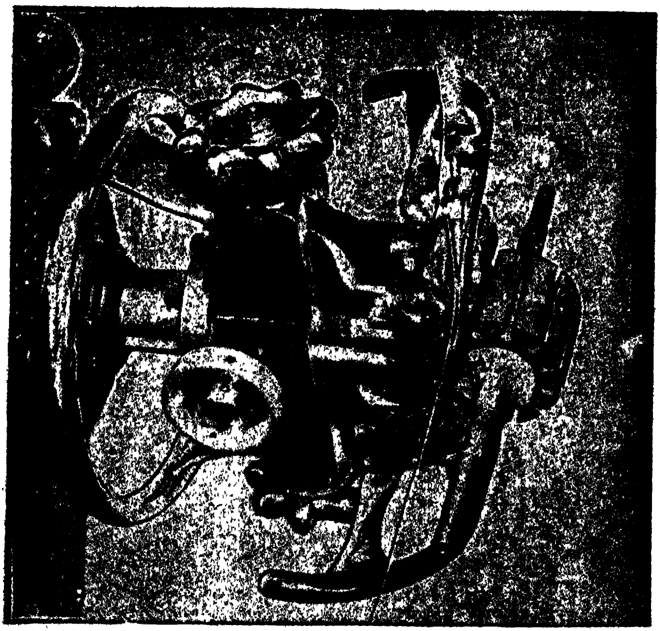


FIG. 654.—Chapman winding head with wire threaded ready for winding. After the wire has been fed through the tension device, snub it by a turn around the snubbing pin, which is so porportioned that you can break off the excess wire by giving it a jerk. It holds firmly against the winding tension, but is quickly disengaged when wanted. Drop it, for it will go where it belongs.

spool on the spindle provided for it at the lower left-hand side of the machine, as shown in fig. 651. Screw the knurled cone nut home against the spool.

Carry the wire up and over the take up arm at left, thence

(unless it be No. 28 B & S or finer wire) down, and loop it around the lower tension pulley, *crossing it* (it will not rub itself, for the pulleys are set to prevent); then up, and loop

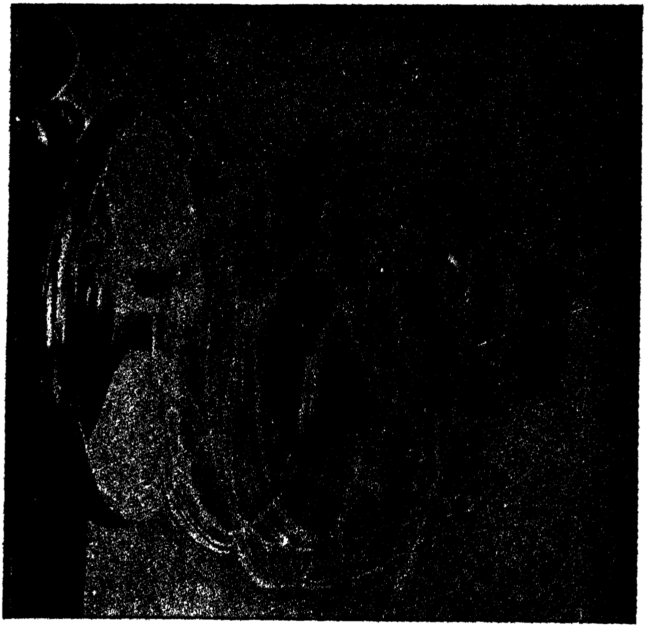


FIG. 655.—*Chapman armature winding, moving picture 1. Machine in operation winding coil.* When the machine is in operation watch the turn counter shown at the top of fig. 651, being careful to stop the machine by releasing the treadle at the right place whereupon the brakes will do most of the work of stopping. Treadle should be released from three to seven revolutions ahead. *Caution,* be sure and get the exact number of turns as a variation always makes a difference and sometimes a surprising difference in the behavior of the finished armature, particularly if it has few teeth or few turns.

around the upper pulley, crossing it, thence down, and loop around the right hand or tension pulley, crossing it again, thence up, *under* and around the little spring mounted forming roller.

The position of this roller laterally has some influence on the

length of the head. Moving it to the left shortens it slightly and increases the tendency to pile up in the corner of the slot.

For wires No. 28 B & S and finer the tension device should be threaded as shown by the dotted line on fig. 651 cutting out the upper and lower pulleys

FIG. 656.—*Chapman moving picture 2.* When the proper number of turns are on, place the finger on the head of the armature; over the first lead. Pull it off the snubbing pin, it will come easily. Pull it down to the left, and slightly upward as shown.

After threading the wire under and around the little forming roller, adjust tension on it by turning the little crank in the center.

Ascertain the tension on the wire by pulling on it *after* it leaves the forming roller, for this little roller, sometimes gives

considerable tension. As a rule, the best tension will (except for plain enamel wire) be $1\frac{1}{8}$ lbs. per 100 circular mils area of the wire. This is close to the elastic limit (stretching point).

It is best to ascertain the tension by means of a spring scale,

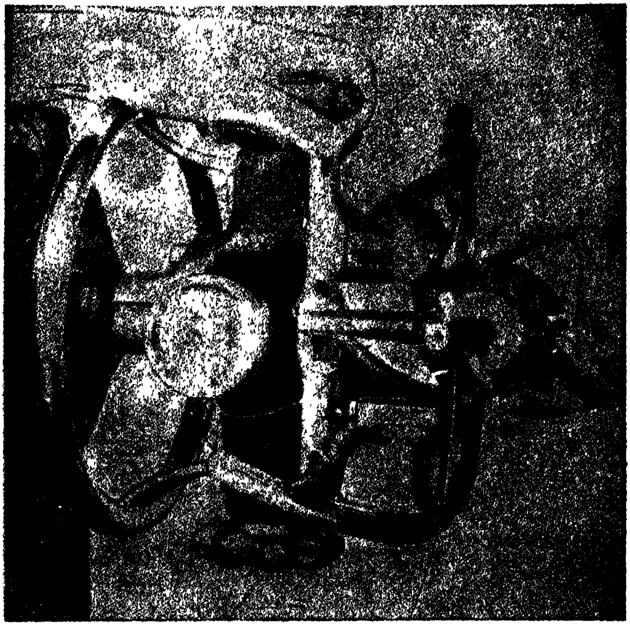


FIG. 657.—*Chapman moving picture 3.* Loosen the armature core, and turn it one tooth to the left. Set the top slot properly with the top jaw. As the back stop has been previously set, pay no attention to the lower slot, for it will now take care of itself. This operation takes only about 3 to 5 seconds.

a fair approximation can be made by increasing the tension till the wire can be felt to stretch, then releasing the tension till the wire does not seem to stretch.

When the correct tension for the particular job is found, a mark may be made on the gear face through the little window,

to aid repetition in setting, which, however, may vary with the temper or hardness of the wire.

The machine winds on the *left* side of the shaft, not on the right. Now put your foot on the pedal which starts the

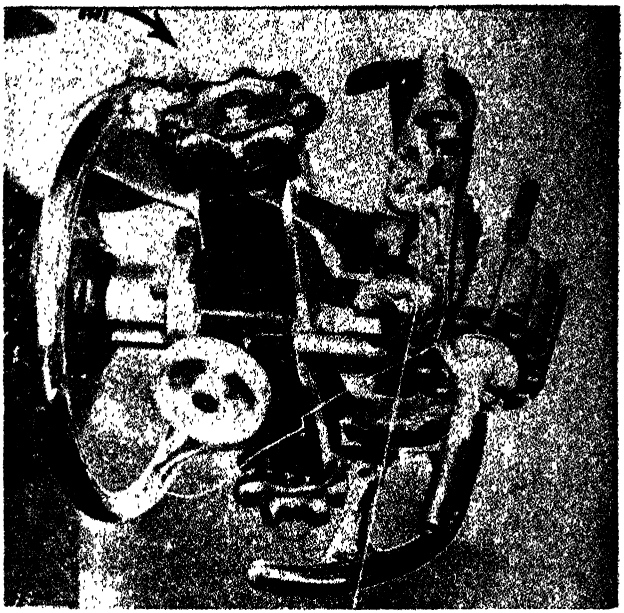


FIG. 658.—*Chapman moving picture 4.* Pull the wire up through the slot in the winding machine jaw, with the right hand, in the meantime backing up with the left until you can hook the wire over the snubbing pin, and let go of it. It will drop in the right place without attention.

machine winding. The rapidity of the winding is indicated in fig. 655.

The accompanying series of illustrations will serve as a *moving picture* showing the operations of machine winding from

start to finish using wire with one or more textile (cotton or silk) coverings.

The turn counter dial at top of fig. 651 is quickly released for resetting by a simple pressure on the screw head in the center thereof. In watching

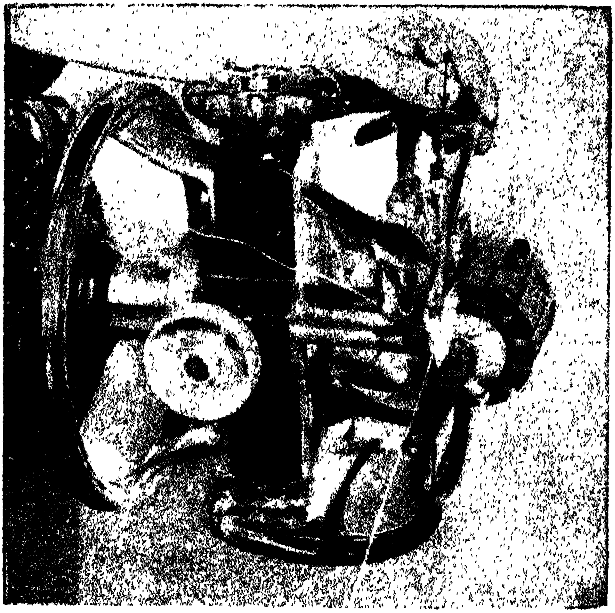


FIG. 659.—*Chapman moving picture 5.* Now twist the lead *after* the coil following it is wound. To catch the idea, view this and the next two pictures rapidly.) The pressure of the thumb tip will automatically unlock the snubbing pin shaft, the skirt of the handle recedes in doing so. It is not necessary to pay any attention to the unlock. Roll the handle by moving the thumb toward the right.

it one should fix in mind the point at which the winding is to *stop* and not the point at which it begins.

When winding armatures having two sections per slot the middle lead is thrown out exactly as shown in fig. 658, when

the slot is half wound, and of course without indexing the armature.

If these leads be properly brought out, the lead between the slots will come out on the right hand side of a coil and that between the top and bottom coils on the left hand side, in other words they will come out in succession for connecting to the commutator.

FIG. 660.—*Chapman moving picture 6.* Keep going. Hold the pressure on the skirt of the handle until after the first turn is completed, then —— (see fig. 661).

If commutators be crowded tight against the windings it is necessary to remove them before winding, if there be a little clearance between the winding and the commutator it is unnecessary to remove them. Should the commutator then interfere with the winding wire, cover it with a piece of paper, or better still, half coated tape, dry side out to keep it from scratching the wire.

Points Relaitng to Enameled Wire Windings

1.—The enamel must be a good grade, for if it be a little under standard, it cannot be used for winding armatures.

2.—The wire must be wound on the armature without tension (as near as possible). There must be no jerks, as by starting the spool to rotating. Therefore the spool can not be revolved by the pull of the wire, for the

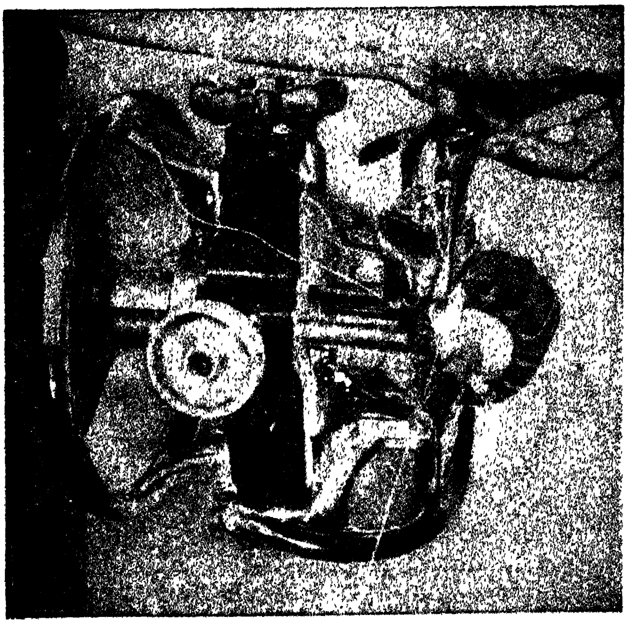


Fig. 661.—***Chapman moving picture 7.*** About the finish of the last turn, the pressure of the hand will be almost automatically transferred to the tip end of the handle, when it will again lock up. Time for twisting the leads, as shown in this and the previous two pictures, about one second. On coarser wires, say 20-26, twisting is unnecessary. Pull the lead off the snubbing pin, the same way as shown in fig. 656, it will come easily, as the pin is carefully proportioned to accomplish this end, and has been automatically stretched during the twisting. Pull the lead down under the jaw to the left, and upward as shown. Move armature over another tooth, and hook the wire on the snubbing pin as before, the operations of course are repeated until ready to finish filling the first slot, as shown in fig. 662.

pull due to inertia at starting gets high enough not only to damage the insulation but to actually break the wire. The friction of the best bearings even gives too much pull.

3.—A space factor must be used, that is, there must be plenty of room both in the slot and on the head.

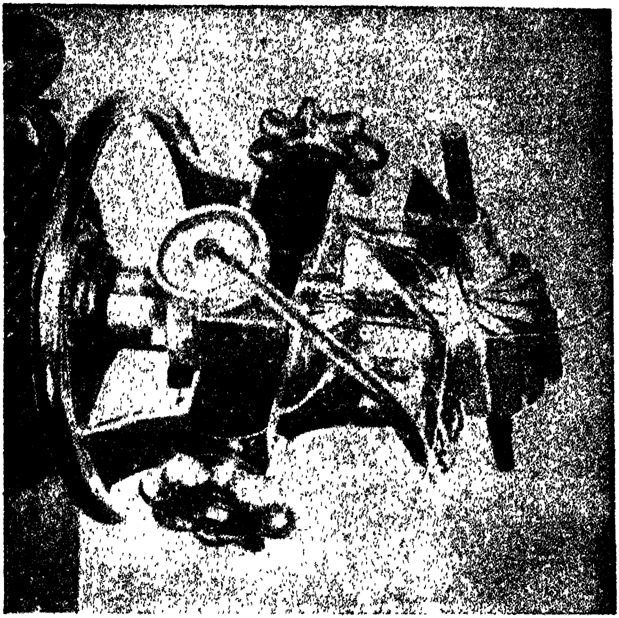


FIG. 662.—*Chapman moving picture 8.* By pulling the first end out at this time, it will meet the last one at the finish and close up perfectly, then resume winding.

4.—There must be no manipulation of the wire after it is wound; it must *not* be pressed, pushed, moved, crowded, pounded or hammered, not even lightly with the fingers.

5.—That the wire must not slip or slide into place, which means that only the chord type of winding can be applied to enameled wire wound armatures.

6.—This chord must be short enough so that the shaft practically does not interfere with the winding, but the chord must not be so short as to approach the span of the pole piece.

7.—The proportion of the winding must be such that the wire may be fed to the slots with very little contact against the winding machine guides, which means fed straight to the armature slots.

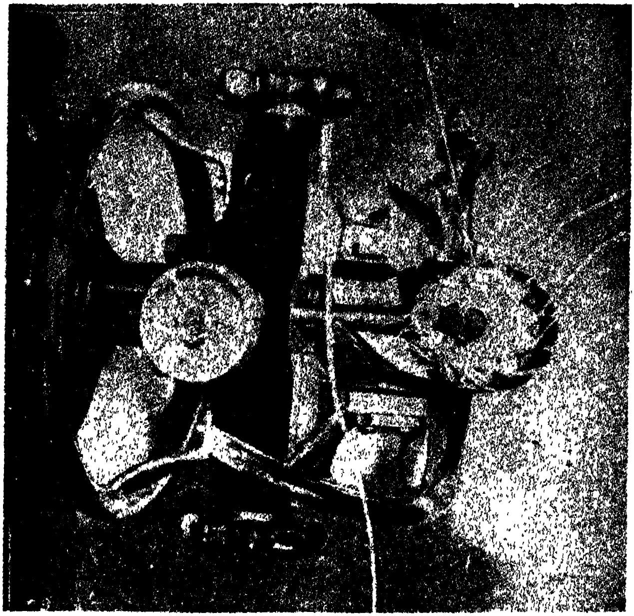


FIG. 663.—*Chapman moving picture 9.* When the last coil is in, cut the wire, and twist the final end with the first end. If the first end has pulled out at the proper point, they will match up as shown, completing the winding, and will be in proper succession for connecting to the commutator.

8.—The wire must be fine, No. 32 B & S being about the largest; coarse wire armatures cannot be successfully wound with enamel wire made at the present date.

9.—There must be no criss cross turns or loose wires.

10.—Auxiliary insulation between top and bottom coils on the heads is always desirable and will increase the life of the armature. Sometimes

it is absolutely necessary, the same is true of insulation between the coils on the heads.

11.—Armatures are best when thoroughly impregnated with varnish and preferably baked. This is however a difficult problem and some makers side step it and don't varnish them at all.

12.—The varnish must be selected to fit each type of enamel, as their solvents must attact the enamel slowly enough (if at all) to permit of its application.

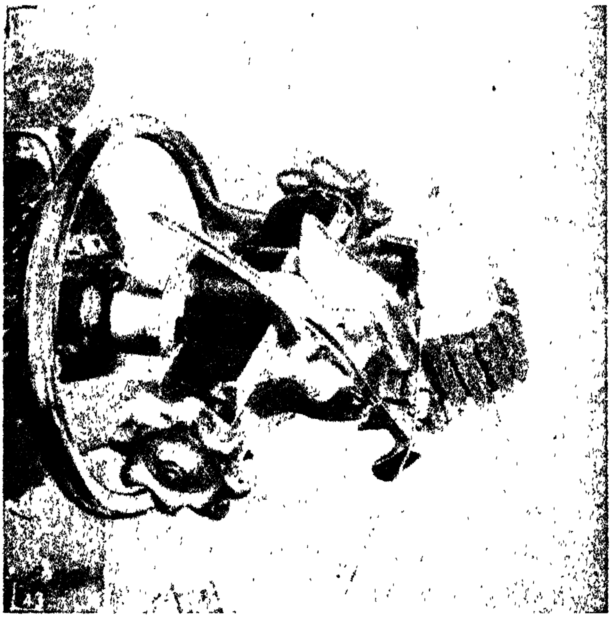


FIG. 664.—Chapman winding machine adjusted for twisted slots. *To adjust*, loosen set screws with a screw driver as shown, but let the cap screw alone, it is a pin and is purposely made with a different head to prevent it becoming loosened and working out. After the two set screws are loose, the jaws can be moved around to match the bevel in the slots of the armature, after which tighten them. In the base of the wings will be noticed two slots playing over the retaining screws; loosen them and move the wing in the same direction that the jaws have been moved that is to say, if the jaw be twisted to the right, then move the wing to the right; if jaw be twisted to the left, then move the wing to the left. If the wire do not behave on entering the slot draw it across the wing, when the remedy will readily suggest itself. If the wing be too far in, no damage will be done except where it is desired to pack the slots full, then the wire in passing over the steel jaw may receive a slight belly, which of course, will be in the wrong direction and tend toward filling the slots with "wind."

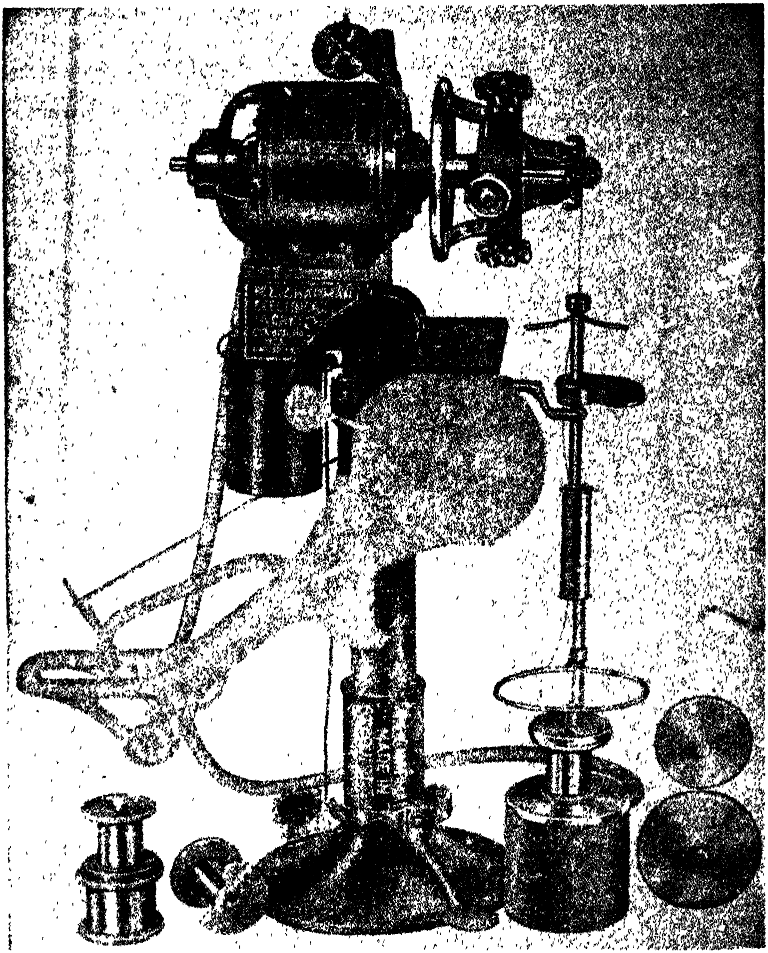


Fig. 665.—The Chapman style 3 adjustable bipolar drum armature winding machine fitted with a Chapman compensating tensionless dereeler with hand rest and self threading wire directing guides for winding armatures with enamel wire. In winding enameled wire armatures the tension must be almost nil and it requires a radically different reel handling device than that required when winding wires with textile covering where a high tension is required.

ding machine. *The machine* is ad-
r drum armatures wound with No. 20
endent of the amount of wire on the
require pounding, frequently making
y hand in layers.

wire or finer and using random windings. Uniform tension is kept on the wire, 1
spool and independent of the speed used, hence the coils are tightly wound and do
it possible to fill the slots with as many or more turns as when the wire is wour

13.—Armatures must not remain in the varnish longer than absolutely necessary to penetrate the windings for the enamel is nearly always attacked by the solvents of the varnish.

14.—Core insulation should fit the slots pretty closely; the wire will not pull it into place, if it did it would injure itself. Sharp crosses between the coils should be avoided, therefore it is better not to design armatures with a very small number of slots as 5 or 7.

15.—Other unexpected things are liable to show up, watch out for them.

Commutator Connection.—Before winding, the commutator should be tested for grounds and short circuits. After winding, the next operation is to connect it to the commutator. On armatures, there are two general types of windings, commonly called "diametrical" and "chord." In the bipolar diametrical type, the two sides of a coil are laced in slots located on a diameter of the core, that is located on any line passing through the center of the core, and through the center of the slots as in fig. 673.

If the commutator be connected up without lead, connecting this type of winding is very simple, for all that is necessary is to remember that the mica between any two segments corresponds to the center of the coil that is connected between the two segments in question. This mica, then, for straight out winding, should be directly in line with the average center of

the slot. This rule is so stated, because in twisted armatures, the slot at the end of the core is not the average center. The mica should in this case be set in line with the center of the slot at the center of the core.

Of course, if the commutator have "lead," that is, if the

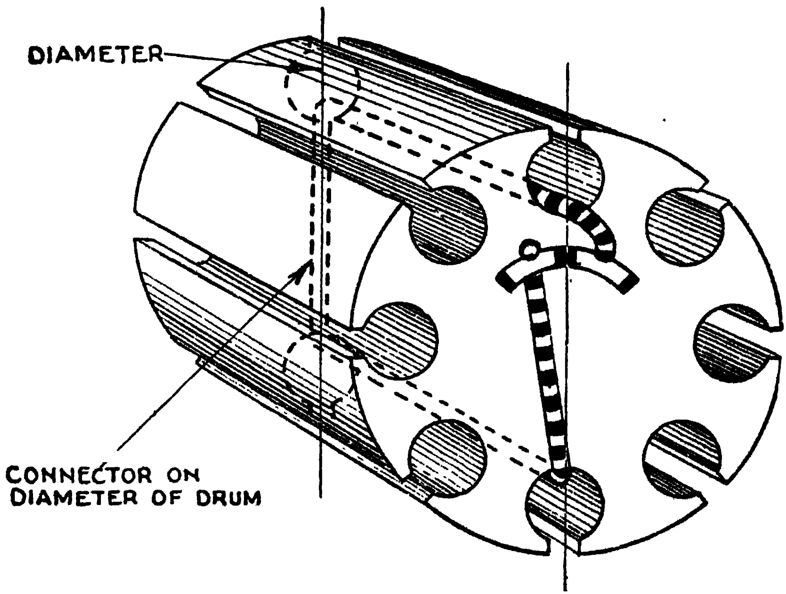


FIG. 673.—Diametrical winding connected straight out for brushes between the poles. The illustration indicates that the coil ends are on diameters of the drum; of course, *in the actual machine*, the coils of necessity pass to one side of the shaft.

brushes be not placed in the polar gap or between the pole tips, this rule should be modified by moving the commutator the amount of this lead, using the points mentioned as a measuring point. This of course will place the commutator mica for 90° lead directly in the middle of the coil.

The "chord" or second type of winding, sometimes called "short coil," is the prevalent type on small armatures.

It is one wherein the two sides of the coil lays in two slots which are not on a diameter, but are on a *chord*, that is a line passing through the center

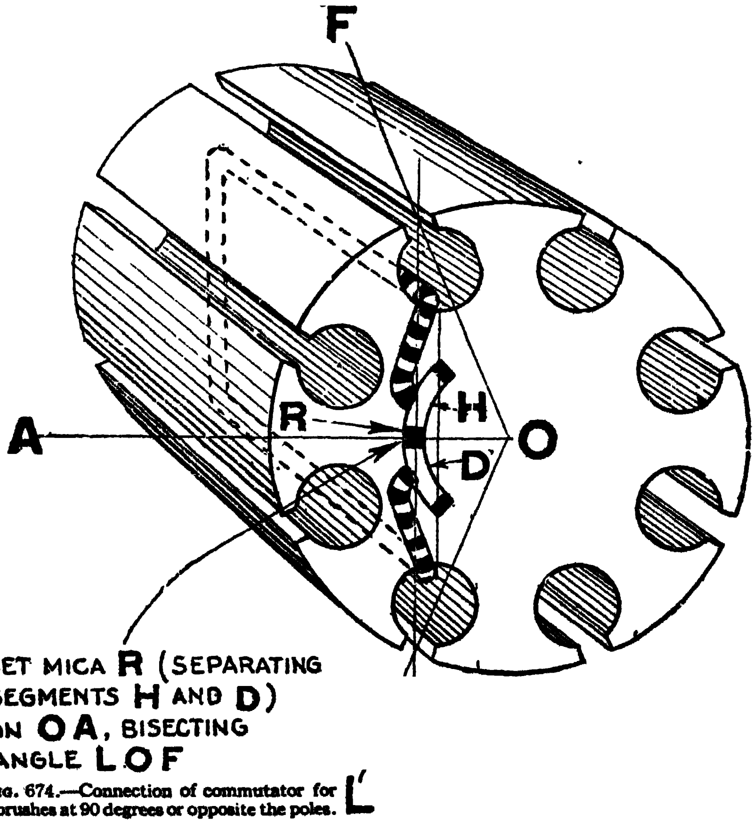


FIG. 674.—Connection of commutator for brushes at 90 degrees or opposite the poles.

of the two slots in which a coil is placed, but not passing through the center of the armature. The above rule for setting a commutator does not apply in this case. Let the reader remember that a chord wound coil will behave

(as far as commutation is concerned) exactly the same as if it were on a diameter which is parallel to the chord on which said coil is wound.

It therefore follows that the mica corresponding to the coil in question, must *not* be placed opposite the average center of the slots in chord wound armatures, but on a *diameter paralleling* the chord. In other words, as the ordinary chord winding is one tooth off the diameter, the mica must be placed one-half tooth away from the slot accommodating the coil, for

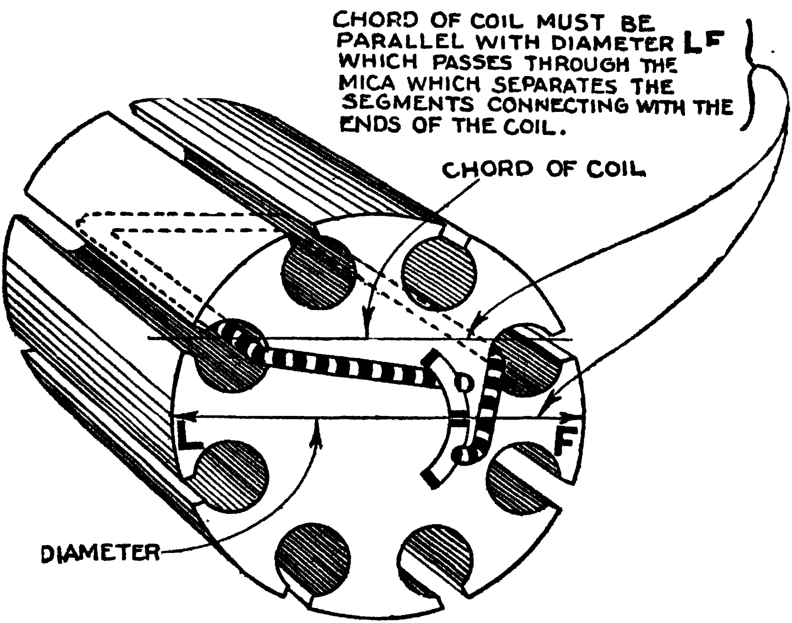


FIG. 675.—Chord winding connected "straight out" for brushes between the poles. Even number of teeth. Displacement of coil, one section; of commutator, one-half section.

straight out connection as in fig. 675 and of course directly opposite the middle of the coil for 90° lead as in fig. 674. These simple rules, if carefully mastered, will solve the problem of connecting any type of armature whatever, including all freak types, as well as the more ordinary drum and ring armatures. It also applies, whether the commutator have many or few sections.

If there be an odd number of teeth in an armature, and the chord be ½ tooth off the diameter, then the commutator will be placed only ¼ tooth away from the coil (see fig. 676). An easy rule is as follows, ***the mica of the commutator should be moved away from its coil one-half of the displacement of the coil from a diametrical position.***

In a properly wound armature the leads will come out opposite the teeth or between the coils, as shown in fig. 677.

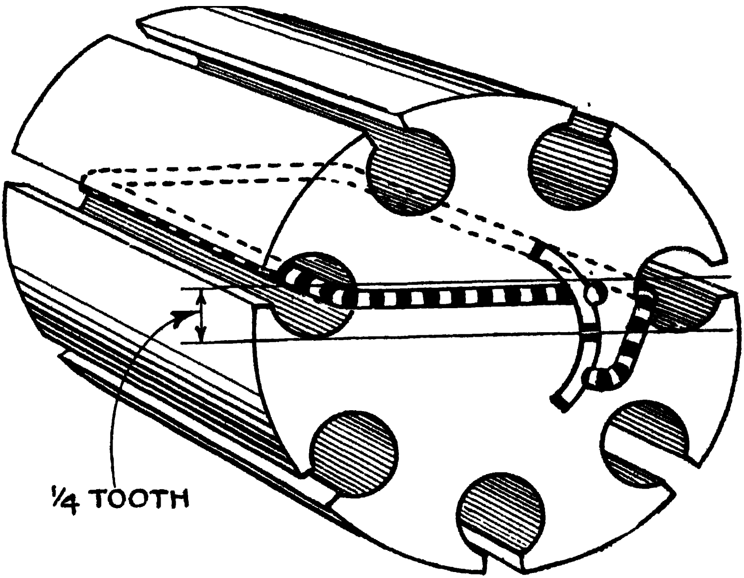


FIG. 676.—Chord winding connected "straight out" for brushes between the poles. Odd number of teeth. Displacement of coil, one-half tooth; of commutator, one-fourth tooth.

It is best to use the top coil as a starting point because it is easier to positively identify the two leads from it.

The foregoing explanations have been made assuming that there is only one section of the commutator and one section of winding per slot in the armature. Where there are more sections of winding per slot in the armature, the point of the

commutator that corresponds to the middle of the coils in a slot, is the point to which the measuring should be done.

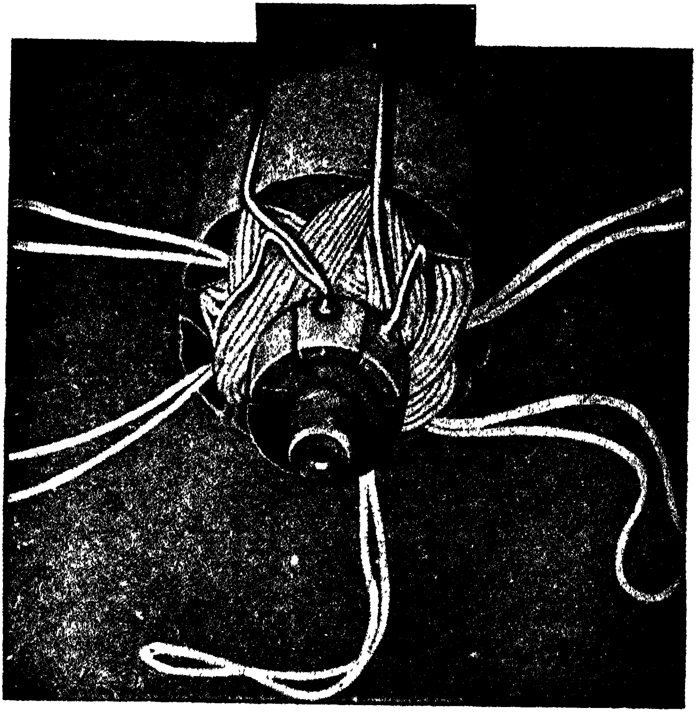


FIG. 677.—An actual armature with connection started, straight out connection. Connected for chord wound coils.

If there be two sections, then it is the segment connected to the middle lead. If there be three sections, the middle mica between the middle leads is the measuring point, if there be four, the middle lead again is the measuring point.

Again if there be two slots in the core per section of the commutator, the mica is again the measuring point. In all cases, measure from the average center of the slot.

Split chord windings or windings in which one side of the coil is placed in two slots making the ends of the coils look like the letter V, are connected straight out, that is, with the mica opposite the average center of the slot accommodating the full half of the coil.

If the commutator should have a lead, measure the angle from the point specified.

The symptoms of incorrect commutator lead are sparking and fusing at the brushes, an irregularity in the torque of the armature from tooth to tooth. It seems to want to *hang up* or stick on every tooth, the torque goes down, and if the lead be 90 degrees off, it goes to nothing, and will not pull at all. The current, in all cases, goes up, and the efficiency down. If the lead be backward, that is, the neutral is carried back under the brushes, it may flash over.

If it be a shunt or compound motor, the speed goes *up*, and if badly off, may run away.

In case of a series motor, it will run slow (when loaded). The armature and fields get hot, and it will not come up to speed. Except for the flashing, these symptoms are usually more apparent in cores of a few teeth.

These comments apply in general to toothed armatures, but the same rules apply to surface wound armatures.

Universal and very high speed commutators frequently have considerable lead. Owing to the fact that they work in very weak fields the shifting of the neutral point or brush lead is excessive.

The lead of the commutator then being shifted instead of shifting the brushes with the consequent non-symmetrical appearance. Great pains should be taken in getting this lead correct.

Soldering the Commutator.—In connecting the leads to a commutator be very careful that no tension is applied to the leads either by soldering them tight or by subsequent hooding or handling. If they be tight, they will break off at the commutator after a few hours' or days' run without any

apparent cause. If the armature be a very high speed geared one, twist the leads tightly before connecting, otherwise do not.

Solder.—The most popular solder for electrical purposes is 40-60, meaning 40% tin and 60% lead. This has a little higher melting point than ordinary tinner's "half and half" but still works freely and costs a little less.

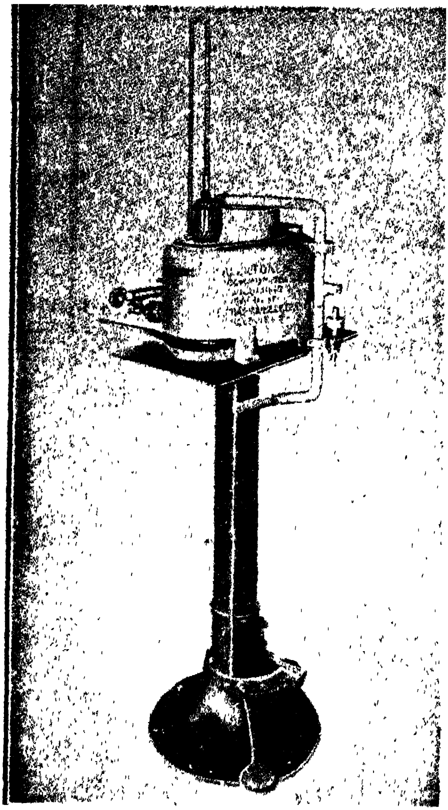


Fig. 678.—Chapman "allatonce" commutator soldering machine. It will solder all sections of a commutator at once, whether fluxed with rosin or any other flux.

Flux.—Raw or diluted muriatic acid or raw muriatic acid cut with zinc ***should never be used as a flux.***

Use for coarser wires a solution of any of the commercial soldering salts which are mostly chloride of zinc. Will not corrode after heating; will work where other fluxes fail; cannot be burnt by too hot solder and the solder never corrodes loose from the copper.

"Soldering pastes" are used for coarser wires and consist of chloride of zinc, but carried by a greasy vehicle. They must not be

greatly overheated or they are liable to carbonize and insulate the joint Work must be fairly clean.

For fine wires No. 30 and smaller. *Use nothing but rosin.* Rosin does not corrode under any circumstances, and it is an insulator. It requires more care in use than other flux. Make a solution of it with alcohol or any one of a number of solvents.

Work must be good and clean; rosin will not work on dirty surface. Care must be exercised not to burn it for it burns into charcoal readily, making a bad joint which must then be cleaned mechanically before it can be soldered. Likewise the temperature must not be too low, else an insulated joint may occur instead of a soldered one.

Rosin is slower in action and requires that the solder be "sweated in" for a longer time. Where rosin is required, it is better to solder commutators on a machine, although the volume of production might not otherwise warrant one.

The time honored method is of course to solder with a soldering copper erroneously called a soldering "iron" sometimes aided on large work by directing a clean flame against the commutator if it can be done without the flame touching insulation (except segment mica). Machine soldering is, however, superior and faster.

Varnishing.—If the weather be damp or wire and insulating materials be stored in a damp place, the armature should be baked or dried before varnishing.

Just before varnishing an armature it should be tested for balance and if out, the heavy side should be placed *up* to drain and bake, the varnish will then tend to correct the unbalance. After baking the armature should of course be balanced.

Thoroughly impregnate the armature with some good baking varnish and bake per directions of the makers. The reason the modern small armature with high voltage and no auxiliary insulation in each slot, stands up so well is largely due to the excellent insulating properties of modern *baking*

varnishes, but the varnishes must penetrate the armature completely or the voltage will be sure to break down the insulation of the unimpregnated part sooner or later. The high dielectric strength of enameled wires helps very greatly and those smaller than No. 23 having one of their covers of enamel are to be preferred for this reason as well as their heat resisting qualities. There are many good varnishes but owing to the fact that enamels are themselves applied as a liquid varnish to the wires, the varnish should be purchased for the purpose from the manufacturers, or the varnish solvent may cut the enamel. Do not soak enameled wires in the varnish longer than absolutely necessary.

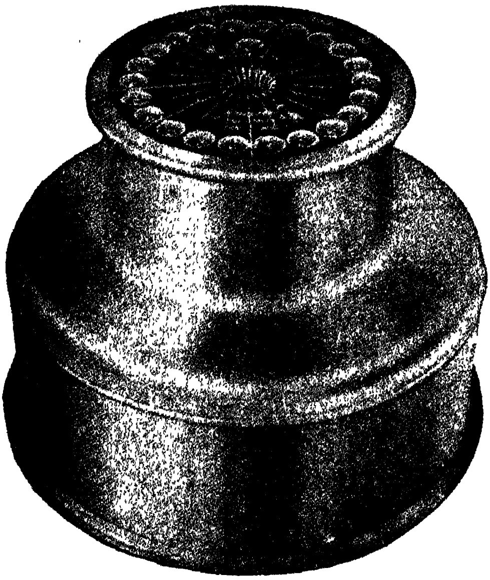


FIG. 679.—Chapman style C ammeter. It indicates the condition of all parts of a wound armature simultaneously; will test the armatures it was built for as specified, will also indicate shorts in double voltage and open circuits on half voltage windings at equal speed. The operator cannot ignore defects. The indications stand out and command attention. A pilot lamp is provided to show the correct reading of the indicators. *To operate*, the commutator is inserted in the fingers in the center of the top whereupon the indicators will light up half way if everything be O.K.; if not, there will be an irregularity in their illumination. This irregularity is what the operator looks for. If a bare commutator be tested, no response is made by the indicator unless a short or ground be present. The odd indicator is assigned to reading grounds at the working voltage of the armature.

Points on Armature Design and Winding.—It is always advisable in designing armatures to allow plenty of room on the heads, particularly when winding with coarser sizes or delicate insulations, as they do not stand hammering very well, and more time is required where it is necessary to pound heads than to wind the wire.

This pounding again reacts in an increased number of short circuits, to prevent which insulation between the coils, and sometimes between layers is required, etc., to prevent this extra cost and trouble design heads with plenty of room.

Excessively deep slots ("all slot" armatures) are to be avoided if possible, they usually have insufficient room between the slot and the shaft for the heads of coils.

An aggravated instance was one having a slot 3/8" deep 1/4" wide with 1/16" space between shaft and slot in which to put insulation and the wire from four coils. To overcome this it is necessary to subdivide the winding, going around more than once, sorting and paring leads after winding (not necessary with regular windings), or use some other objectionable stunt. In one instance the coils were wound in the top of the slots, leaving the bottom clear.

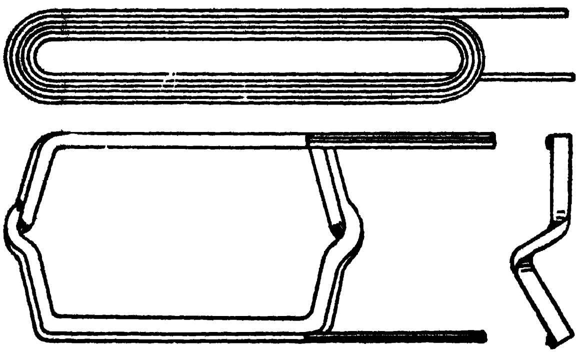
Round slots are seldom used now.

In selecting the number of teeth for very small and medium armatures, it is always best (in fact on any of them) to select an odd number of teeth, as this arrangement has only one section of the core and the commutator commutating at a time, the action then is smoother. This gives a chord winding, the heads will go on without piling up excessively.

Long experience has dictated that .100" to .125" is about the best all around width for armature slots at the surface of the core on all sizes from 1/2 horse power and even larger, down to the smallest. This width works nicely on a winding machine, is wide enough to give a little leeway, to accommodate the insulation, prevent excessive magnetic slot leakage, and makes inappreciable difference in the effective air gap between this size and a narrower one. Designers can unhesitatingly use this size of slot on all the smaller sized cores.

If the magnetic field were a perfect sine field, the effect of a chord winding would be to reduce its effectiveness by angle enclosed by coil, that is,

$$\text{effectiveness} = \frac{2 \sin \times \text{effect of a diametrically wound coil}}{\;}$$



FIGS. 680 to 682.—Method of making preformed armature coils. First, for a diamond shaped coil a *long narrow coil* is wound as in fig. 680, which is commonly called a *hair pin loop*. This is put on a coil forming or pulling machine and pulled into shape as in figs. 681 and 682, the pulling machine being shown in fig. 683.

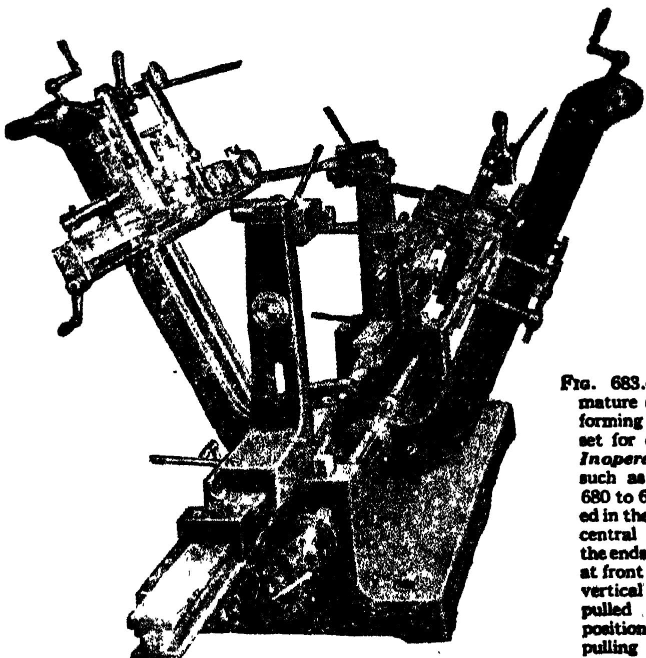


FIG. 683.—Peerless armature coil pulling or forming machine, as set for diamond coils. *In operation,* windings such as shown in figs. 680 to 686, are inserted in the holders on the central vertical arms, the ends in the knuckles at front and rear. The vertical arms are then pulled apart to the position shown, thus pulling the coil to shape.

(angle referred to circle of reference) but with polar fields, practically the effect cannot be found so long as the pole pieces do not span about the same angle as the coil on the armature or more; if they do so or nearly so, then the magnetic leakage around the coil begins to have a decided effect, more than is indicated by the formula, in fact the effect is tremendous, especially on cores with a few teeth, but in 99 cases out of 100, tne performance of chord windings test out the same as diametrical winding.

Very short chords should be avoided, for they cut down the capacity of the machine, increase magnetic leakage, and sometimes make them misbehave decidedly. While a very short chord has a tendency to make small heads, if it be too short, nothing will be gained, for the windings will pile up in a ring, and leave a hollow space around the shaft, also pile up on the side of the slot interfering with coils in the bottom of neighboring slots.

Designers have frequently made their armatures with excessively short chords, in order to make it possible to wind the armature on some crude winding device. This is unnecessary with a good winding machine, except possibly when using plain enameled wire.

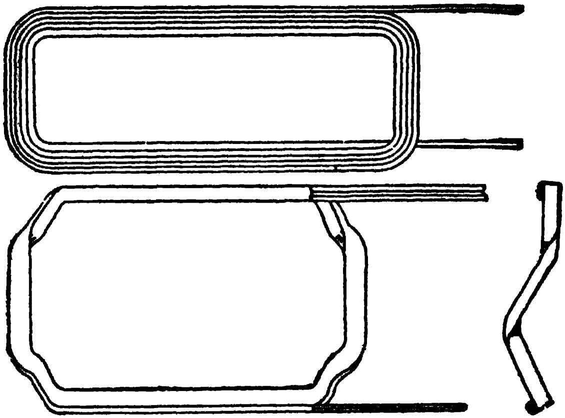
Straight chord windings, that is, those which occupy only two slots whether having one or more leads, if properly connected, are superior to split chord windings, that is, all the coil in one slot one side of the armature, the other side of the coil in two separate slots, passing on two sides of the shaft making the end of the coils look like the letter V.

Cases have been known where a V winding reduced the output 50%. They are slightly more noisy, with accompanying "lumpy" torque. If the winding be subdivided into two coils per slot it may make everything worse, the coils and the commutator then being badly out of phase, for example, position with each other producing vicious sparking on every other segment of the commutator. Armature heads are usually the same size. V windings require special armature winding machinery.

Initial or uncorrected balance (mechanical) seems to be the same except in the case of small numbers of teeth, say 7 or less, when the V winding exhibits its only good quality.

Owing to the very great dielectric strength of modern baking armature varnishes it is seldom that insulation is inserted between top and bottom

coils in the same slot on small armatures. On 500 volt armatures it is, however, absolutely necessary, as well as between the top and bottom coils on the heads and sleeving required on the leads.



FIGS. 584 to 686.—Forming of *short coil*. FIG. 684, shape of winding before pulling, figs. 685 and 686, same after pulling. This type of coil is extensively used in Westinghouse apparatus

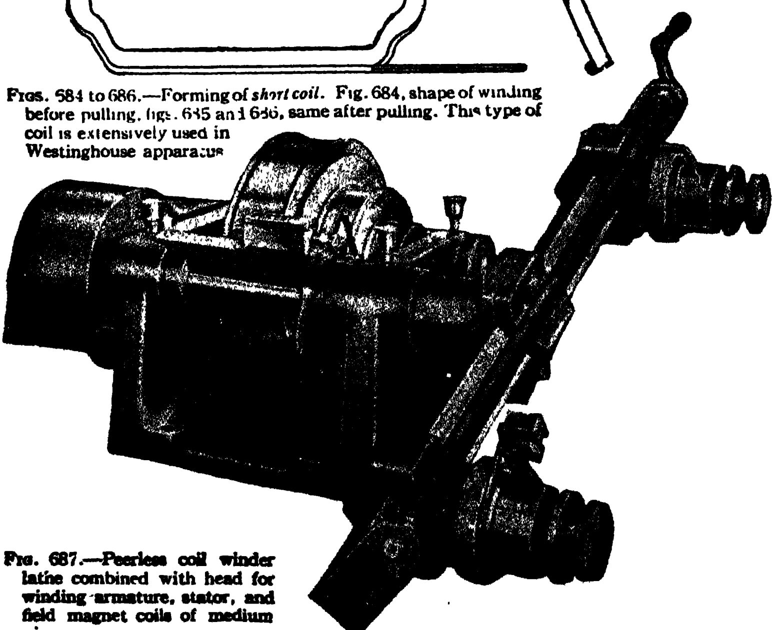
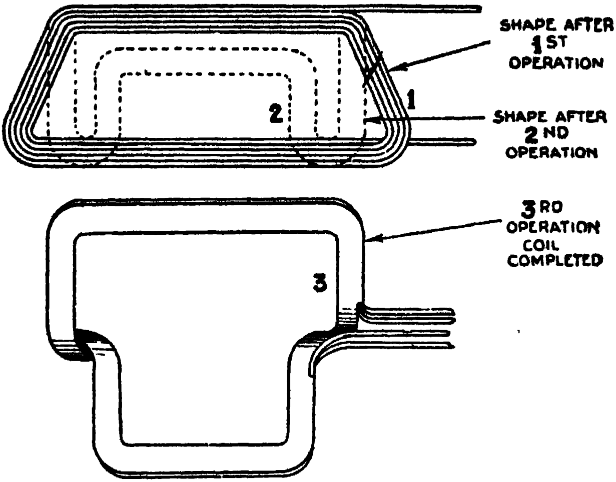


FIG. 687.—Peerless coil winder lathe combined with head for winding armature, stator, and field magnet coils of medium sizes.



FIGS. 688 and 689.—Method of making Eichmeyer coils. The coil is first wound to the shape 1, and then the second operation which requires special tools for its performance, shapes it as shown by dotted line 2. The coil is then pulled out angularly to the shape . . A better and faster method where quantities of Eichmeyer coils are needed, is to make a jig with stepped pin for the two inner corners and wind the coil directly to shape in fig. 6 , (2) then pulling them to their final shape. This method does not strain the insulation so severely and is much faster. After the coils are pulled, they are usually taped where they go in open topped slots; where they are threaded in slots with narrow openings one wire at a time they cannot be pre-taped to any extent. Practice varies as to varnishing the coils before assembling in the armature. Sometimes they are varnished before pulling on the machine; frequently after pulling and before taping, occasionally after taping and before assembling and sometimes not till after assembly. Threaded in coils cannot be pre-varnished. Varnishing before assembly usually requires that the coils be heated enough to soften the varnish and then pressed in a *cold* forming die in order to get them small enough to go into the slots. For this reason it is seldom that repair shops varnish the coils before assembly.

NOTE.—***Most preformed armature coils*** and many stator coils are taped with a *layer* of cotton tape "in the white" that is not varnished, oiled or gummed. Most popular size is ¾″ × .007″. This tape is usually applied half lap. Where, however, some of the slot insulation is applied to the coil the tape is usually over it and then is frequently applied "but lapped." or a single thickness over this slot insulation. Machines are almost universally used for taping coils now both in the job shop and factories. After the coils are taped the factories usually varnish them before assembling. Repair shops usually assemble them in the white, as pre-varnished coils sometimes require pressing before assembling.

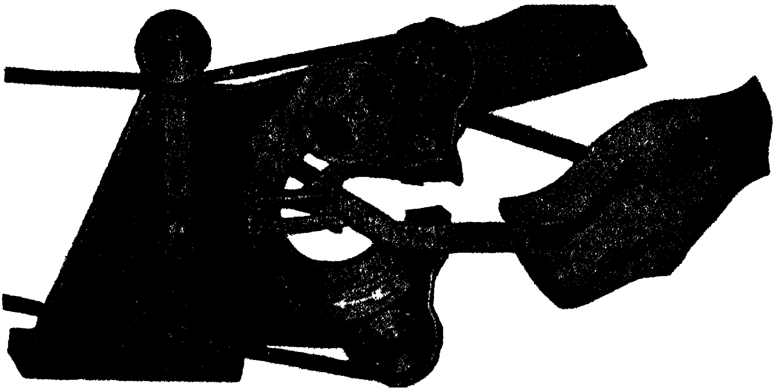


FIG. 690.—Chapman kickless self feed armature coil taping machine. Takes a considerable amount of the "kick" off the operator's hands. Eliminates the excessive fatigue of operator due to this kick. Does not interfere with the handling of the coil around the loops. Self feed is as nearly positive as can be (about 80%) and still allow the operator to increase or decrease lap at will while running. Feed can be varied to obtain a variety of laps, but is set at half lap for ¾" tape applied to the average armature coil when it leaves the factory.

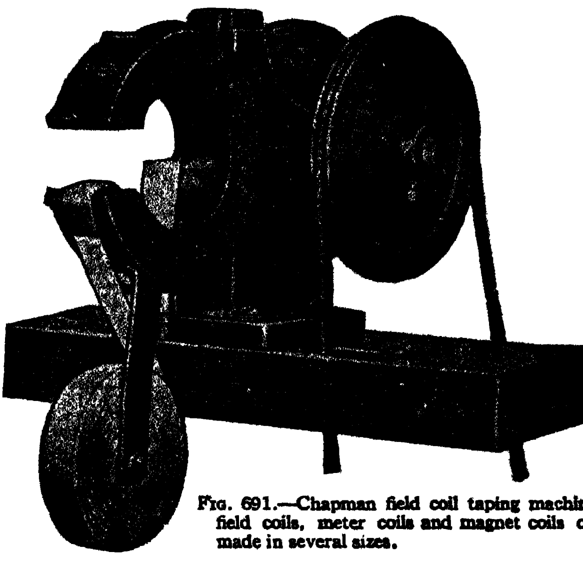


FIG. 691.—Chapman field coil taping machine for taping field coils, meter coils and magnet coils of all kinds made in several sizes.

RE-CONNECTING D.C. MACHINES

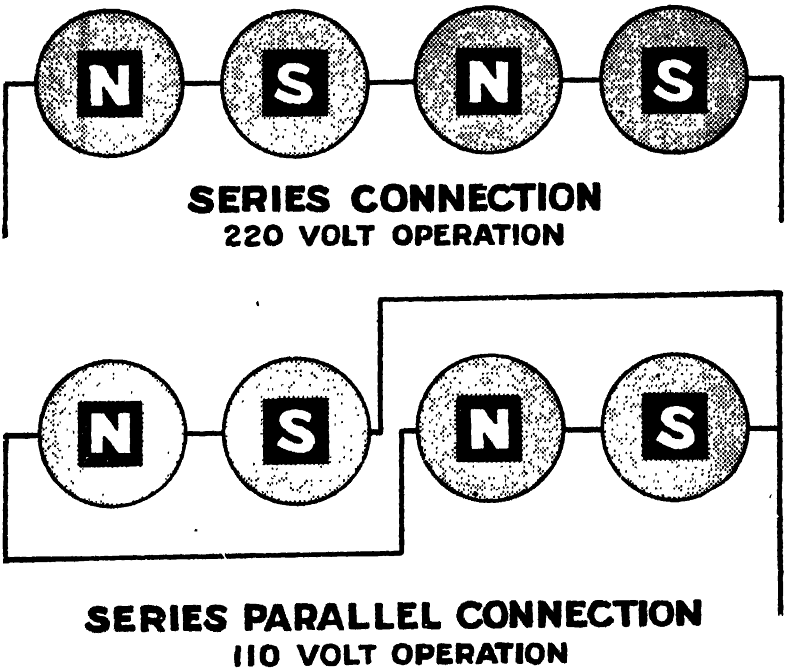
Repairmen are frequently called upon to make changes in a dynamo or motor such that the machine can be operated at a different voltage or speed, and sometimes to adapt a dynamo for use as a motor, etc.

FIG. 692.—Peerless portable band wire tension machine applied to a lathe. *It consists of* a friction tapered drum so designed that it neutralizes the tendency of the wire to creep. The amount of tension is under perfect control of the operator and is regulated by ten point index. *In operation*, each pound applied to the brake drum is multiplied by means of gearing to 3 lbs. at the band wire drum, which is tapered to compensate for the tendency of the wire to crowd up against the flange. On account of this gear reduction, a comparatively small braking effect produces a very great tension on the band wire, and any change in tension can be secured by regulating the hand nut, directly in front of the operator.

Voltage Changes.—In making changes for motors or dynamos to operate on different voltages it should be noted that the speed of a motor varies directly with the voltage provided the field remains constant.

The variation of voltage affects the excitation of the fields, and until saturation is reached, the speed varies little with change of voltage. Small speed changes may be effected by changing the length of the air gap.

Changes for Half Voltage Operation.—Arrange the shunt field coils in two groups and connect the groups in parallel.

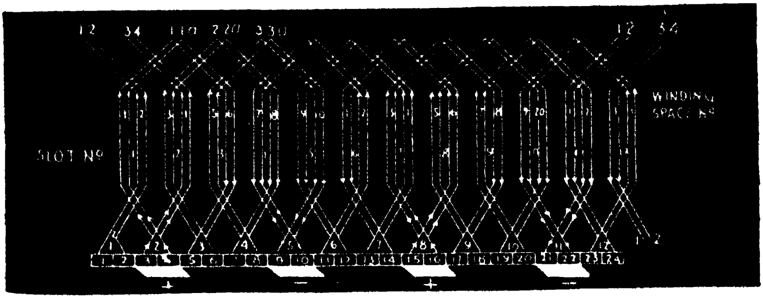


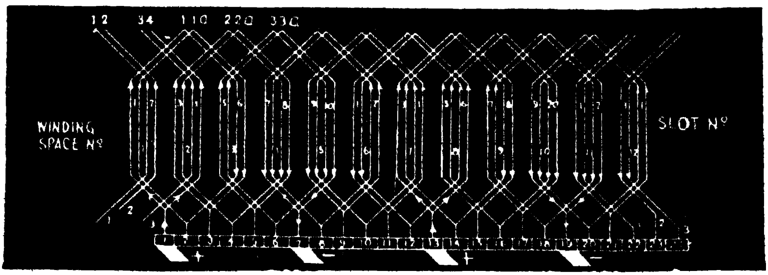
FIGS. 693 and 694.—Changes in field connection for half voltage operation. Connect shunt field coils in series parallel as shown in fig. 694 Here, as is evident, the shunt field resistance is reduced one-half permitting the same field current to flow at half voltage.

With this arrangement evidently on half voltage circuit, the voltage per field coil will be the same, hence the flux will be the same but the speed will be only half what it was before the changes were made.

Armature Winding Changes for Voltage Changes.—An armature can usually be adapted to a lower voltage either by reconnecting or by rewinding.

In making changes it should be noted that the sectional area of the wire





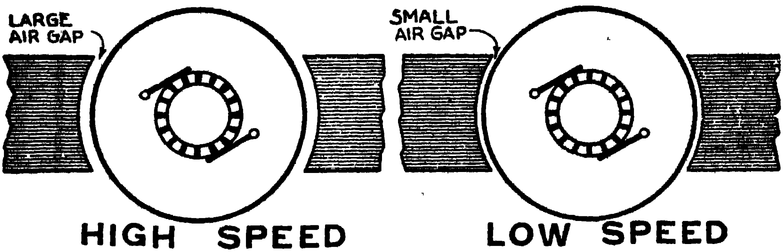
FIGS. 695 and 696.—Duplex lap winding for 120 volts, and method of reconnecting for 240 volts. On armatures having duplex windings there are usually twice as many commutator bars as there are slots and each of the two wires is connected to separate bars. The brush will however cover at least 1½ to 2 bars To change from 120 to 240 volts, reconnect the winding so that adjacent pairs of coils will be in series as in fig. 696 instead of in parallel as in fig. 695, and reduce width of brushes to that of one commutator bar.

for the coils varies inversely and the number of turns directly as the old to the new voltage. In determining the form of coil and number of turns to be used in rewinding, the slot space available must be considered.

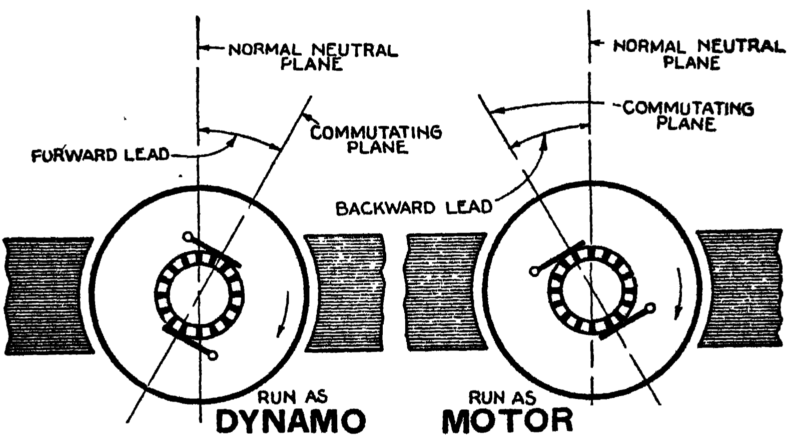
Changes for Double Voltage Operation.—The shunt field coils

must be rewound in this case using wire of half the cross sectional area (three sizes finer) and twice the number of turns.

The compound series fields, if any, will work as they are, but to preserve same regulation as before, must be given the same treatment; the shunt fields remaining in series. However, the armature is used without alteration.



FIGS. 697 and 698.—Method of changing the speed of a motor by adjusting the air gaps.



FIGS. 699 and 700.—Machine operated as dynamo and as motor. When the machine is operated as dynamo the brushes should be given *forward* (positive) *lead*, and when operated as a motor, *backward* (negative) lead.

Speed Changes.—Major changes must be made by changing the number of turns and the size of wire on the armature. Speed with a fixed voltage will vary inversely as the turns.

Minor speed changes may sometimes be made by adjusting the air gap of the motor. The variation in speed obtained by this method is from 10 to 15%. To increase speed, increase air gap; to reduce speed, reduce air gap, but don't get it too small or the commutator action will be rendered unsatisfactory and other troubles will develop.

Dynamo Operated as a Motor.—The machine will run in the same direction, but in the case of a compound machine, the series winding should either be cut out or reversed, and the field rheostat removed. When the load comes, move brushes backward that is, opposite to the direction of rotation.

If the series field be not cut out, it must be connected in the same direction as the shunt coils, usually requiring them to be reversed. When the load is applied, the brushes will require shifting in the direction of rotation.

Direction of Rotation.—Reversing the armature connections will reverse either a dynamo or motor unless it be a machine with interpoles; in this case the interpoles and the armature must be reversed together.

Reversing the shunt and if compound, the series field (but not any interpole field) will reverse the rotation.

If either the rotation of the armature, or shunt field connections of a dynamo, be reversed without an accompanying reversal of another element, the magnetism induced by the winding will oppose the residual magnetism and the machine will not build up. A multipolar machine can be reversed by reversing the brushes on the studs and then relocating them.

Wrong Field Connections.—Sometimes due to error in the shop a motor may have one or more magnets reversed, resulting in little or no torque. Trace out connections or test polarity of magnets by means of a compass, the little ones used by watch makers are the best.

Carbon Brush Maintenance and Trouble Chart

An Analysis of Causes and Effects of Brush and Commutator Troubles in Direct Current Motors and Dynamos

CAUSES OF BRUSH AND COMMUTATOR TROUBLES	EFFECTS AND EVIDENCES OF TROUBLES															
	Sparking	High Mica	Flat Spots	Commutator Heating	Armature Heating	Black Commutator	Rapid Commutator Wear with Commutator Black	Rapid Commutator Wear with Commutator Bright	Pitting of Brush Faces	Glowing of Brushes	Picking Up Copper	Noisy Brushes	Loosening of Brush Shunts	Rapid Brush Wear	Burning of Brush Holder Boxes	Loss of Temper in Brush Springs
A. Due to Wrong Grade of Brush.																
1. Sparking		✓	✓	✓		✓	✓							✓		
1. Too low carrying capacity				✓		✓			✓	✓				✓		
2. Too little abrasive action		✓		✓		✓										
3. Too much abrasive action				✓				✓				✓		✓		
4. High friction brushes				✓								✓				
5. Too high contact drop	✓			✓												
6. Too low contact drop	✓			✓	✓	✓			✓	✓				✓		

Trouble Chart—*Continued.*

B. Due to Faulty Brush Operation.

1. *Brushes off electrical neutral*	√			√	√				√	√	√					
2. *Incorrect brush spacing*	√			√	√				√				√			
3. *Brushes too thick*	√			√	√				√	√	√					
4. *Brush pressure too low*	√	√		√		√	√		√	√				√		
5. *Brush pressure too high*				√				√				√		√		
6. *Unequal brush pressure*	√								√	√			√			
7. *Brushes tight in holders*	√	√	√			√	√		√	√				√		
8. *Worn brush holders on machines running in only one direction*													√		√	
9. *Worn brush holders on reversing motors*	√								√	√		√	√	√	√	√
10. *Brushes operated at wrong angle*												√				
11. *Brushes chattering*	√	√		√								√	√	√		
12. *Too high ratio of brushes to commutator surface*				√												
13. *Lubricated brushes*						√										
14. *Loose brush shunts*															√	√
15. *Loose terminal screws*															√	√

C. Due to External Causes.

1. *Overloads*	√			√	√								√			
2. *Surges of load on line*			√													
3. *Cross currents between generators*	√		√	√	√				√				√			
4. *Poor belt lacing*			√													
5. *Pound of engine*			√													
6. *Unstable foundation*	√		√													

Trouble Chart—*Continued; column headings on page 476.*

column headings on page 476.

D. Due to Armature and Field Defects.

1. Loose end connection	√		√													
2. Open circuit in armature coil	√		√													
3. Unbalanced armature winding	√		√	√	√											
4. Mechanically unbalanced armature	√		√													
5. Jammed armature laminations					√											
6. Partial short in shunt field	√															
7. Series field poorly adjusted	√	√		√	√											
8. Series field bucking	√	√		√	√											
9. Poor adjustment of interpoles	√	√		√	√											
10. Unequal air gaps	√			√	√											
11. Worn bearings	√			√	√											
12. Flux distribution	√	√		√	√											

E. Due to Commutator Defects.

1. Brush studs not parallel to commutator bars	√			√	√				√	√			√			
2. High mica	√		√	√		√	√					√		√		
3. High bar	√		√									√		√		
4. Low bar	√		√													
5. Eccentric commutator at high speed	√		√													
6. Rough commutator				√										√		
7. Use of lubricant on commutator				√		√					√					
8. Dirty commutator				√												
9. Difference in hardness of bars			√													
10. Difference in hardness of mica			√													
11 Commutator not properly finished after turning				√										√		
12 Commutator too small				√												

TEST QUESTIONS

1. *What winding data is required by the repairman?*
2. *How is an armature dismantled?*
3. *What should be done after the coils have been removed?*
4. *What kind of mica should be used between the segments?*
5. *What is the objection to hard mica between segments?*
6. *What kind of mica should be used for clamping rings, sleeves, etc.?*
7. *How are riveted commutators opened up?*
8. *Describe the methods of truing a commutator.*
9. *What causes high mica?*
10. *Describe the operation of undercutting mica.*
11. *What is the cause of high and low commutator bars?*
12. *What is the remedy for burn outs?*
13. *Explain how a commutator is dismantled for repairs?*
14. *How is a repaired commutator tightened?*
15. *Describe the construction of a commutator clamp.*
16. *How are cores insulated?*
17. *Describe the insulation of slots.*
18. *How are slots insulated when thick insulation is required?*
19. *Mention a few points relating to magnet wires.*
20. *What are the objections to hand winding of armatures?*
21. *Describe the operations of putting on a two layer lap winding by hand.*
22. *What is used on the leads to avoid confusion?*

23. *Upon what does the "number of wires" depend?*
24. *Describe the operations in winding: 1, two layer lap winding; 2, split V winding; 3, chorded split winding.*
25. *Describe in detail machine winding.*
26. *Explain how the commutator connections are made.*
27. *Describe the operations in making a preformed coil.*
28. *What are the symptoms of incorrect commutator leads?*
29. *Describe the methods of soldering the coil leads to the commutator.*
30. *What kind of soldering flux should be used?*
31. *What should be done before varnishing the armature?*
32. *Give a few points on armature design.*
33. *How are d.c. machines re-connected for: 1, voltage changes; 2, half voltage operation; 3, double voltage operation.*
34. *Describe the armature winding changes for voltage changes.*
35. *How are speed changes made?*
36. *What is done to operate a dynamo as a motor?*

Formulae for Calculating Electrical Properties of Circuits

Desired Data	ALTERNATING CURRENT			Direct Current
	Single Phase	Two Phase* Four Wire	Three Phase	
KILOWATTS	$\frac{I\,E\cos\theta}{1000}$	$\frac{2\,I\,E\cos\theta}{1000}$	$\frac{1.73\,I\,E\cos\theta}{1000}$	$\frac{I\,E}{1000}$
KILOVOLT-AMPERES	$\frac{I\,E}{1000}$	$\frac{2\,I\,E}{1000}$	$\frac{1.73\,I\,E}{1000}$	$\frac{I\,E}{1000}$
HORSEPOWER OUTPUT,	$\frac{I\,E\cos\theta \times \text{Eff.}}{746}$	$\frac{2\,I\,E\cos\theta \times \text{Eff.}}{746}$	$\frac{1.73\,I\,E\cos\theta \times \text{Eff.}}{746}$	$\frac{I\,E \times \text{Eff.}}{746}$
AMPERES WHEN HORSEPOWER IS KNOWN	$\frac{HP \times 746}{E\cos\theta \times \text{Eff.}}$	$\frac{HP \times 746}{2\,E\cos\theta \times \text{Eff.}}$	$\frac{HP \times 746}{1.73\,E\cos\theta \times \text{Eff.}}$	$\frac{HP \times 746}{E \times \text{Eff.}}$
AMPERES WHEN KILOWATTS ARE KNOWN	$\frac{KW \times 1000}{E\cos\theta}$	$\frac{KW \times 1000}{2\,E\cos\theta}$	$\frac{KW \times 1000}{1.73\,E\cos\theta}$	$\frac{KW \times 1000}{E}$
AMPERES WHEN KILOVOLT AMPERES ARE KNOWN	$\frac{KVA \times 1000}{E}$	$\frac{KVA \times 1000}{2\,E}$	$\frac{KVA \times 1000}{1.73\,E}$	$\frac{KVA \times 1000}{E}$
e_r WHEN e_s, I, cos θ ARE KNOWN	$\sqrt{e_s^2 - I^2(X\cos\theta \mp R\sin\theta)^2} - I(R\cos\theta \pm X\sin\theta)$			......

*In three wire two phase circuits, the current in the common conductor is 1.41 times that in either phase conductor.

NOTATION

- $\cos\theta$ = Power factor of load
- E = Volts between conductors
- e = Volts to neutral
- Eff. = Efficiency of motor
- e_r = Volts at receiving end
- e_s = Volts at sending end
- I = Line current amperes
- R = Resistance in ohms to neutral
- $\sin^2\theta = 1 - \cos^2\theta$
- X = Reactance in ohms to neutral

Where double signs, such as $\mp$ or $\pm$ are shown, use upper one for lagging and lower one for leading power factor.

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gauge (B. & S.) English Units

Gauge No.	Diameter in mils at 20°C	Cross section at 20°C		Ohms per 1000 feet			
		Circular mils	Sq. inches	0°C (32°F)	20°C (68°F)	50°C (122°F)	75°C (167°F)
0000	460 0	211600	0 1662	0.04516	0 04901	0.05479	0 05961
000	409 6	167800	1318	.05695	06180	.06909	.07516
00	364.8	133100	.1045	07181	.07793	.08712	.09478
0	324 9	105500	.08289	.09055	09827	.1099	.1195
1	289 3	83690	.06573	.1142	.1239	.1385	.1507
2	257 6	66370	05213	.1440	.1563	.1747	.1900
3	229 4	52640	04134	1816	1970	.2203	.2396
4	204 3	41740	03278	2289	.2485	.2778	.3022
5	181 9	33100	.02600	2887	3133	.3502	3810
6	162 0	26250	02062	3640	.3951	.4416	.4805
7	144 3	20820	01635	4590	.4982	.5569	.6059
8	128 5	16510	01297	.5788	.6282	.7023	.7640
9	114.4	13090	01028	.7299	.7921	.8855	.9633
10	101.9	10380	008155	9203	9989	1 117	1.215
11	90 74	8234	006467	1 161	1 260	1 408	1 532
12	80 81	6530	005129	1 463	1.588	1 775	1 931
13	71.96	5178	.004067	1 845	2 003	2 239	2 436
14	64 06	4107	003225	2 327	2 525.	2 823	3.071
15	57 07	3257	002558	2 934	3 184	3 560	3.873
16	50 82	2583	002028	3 700	4 016	4 489	4 884
17	45 26	2048	001609	4 600	5 064	5.660	6 158
18	40 30	1624	001276	5 883	6 385	7 138	7.765
19	35 89	1288	.001012	7.416	8.051	9 001	9.792
20	31 96	1022	0008023	9 355	10 15	11 35	12.35
21	28 45	810 1	0006363	11 80	12 80	14 31	15 57
22	25 35	642 4	.0005046	14 87	16 14	18.05	19.63
23	22 57	509 5	0004002	18.76	20 36	22 76	24 76
24	20.10	404 0	0003173	23 65	25 67	28 70	31 22
25	17 90	320 4	0002517	29 82	32 37	36 18	39.36
26	15 94	254 1	0001996	37 61	40.81	45.63	49.64
27	14 20	201 5	0001583	47 42	51 47	57 53	62 59
28	12 64	159 8	0001255	59 80	64 90	72 55	78.93
29	11 26	126.7	.00009953	75.40	81.83	91.48	99.52
30	10 03	100 5	.00007894	95 08	103 2	115 4	125.5
31	8 928	79 70	00006260	119 9	130 1	145 5	158.2
32	7 950	63 21	00004964	151 2	164 1	183 4	199.5
33	7.080	50 13	00003937	190 6	206 9	231 3	251.6
34	6.305	39.75	.00003122	240.4	260 9	291.7	317.3
35	5 615	31.52	.00002476	303.1	329.0	367 8	400.1
36	5 000	25 00	.00001964	382 2	414 8	463 7	504.5
37	4 453	19 83	.00001557	482 0	523.1	584 8	636.2
38	3.965	15 72	.00001235	607.8	659 6	737 4	802 2
39	3 531	12.47	.000009793	766.4	831.8	929.8	1012
40	3.145	9.888	000007766	966.5	1049	1173	1276

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Single Conductor in Free Air

(Based on Room Temperature of 30 C. 86 F.)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) / Thermo-plastic Type T Type TW	Rubber Type RH	Thermo-plastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impregnated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA	Slow-Burning Type SB / Weatherproof Type WP Type SBW
14	20	20	30	40	40	45	30
12	25	25	40	50	50	55	40
10	40	40	55	65	70	75	55
8	55	65	70	85	90	100	70
6	80	95	100	120	125	135	100
4	105	125	135	160	170	180	130
3	120	145	155	180	195	210	150
2	140	170	180	210	225	240	175
1	165	195	210	245	265	280	205
0	195	230	245	285	305	325	235
00	225	265	285	330	355	370	275
000	260	310	330	385	410	430	320
0000	300	360	385	445	475	510	370
250	340	405	425	495	530	....	410
300	375	445	480	555	590	....	460
350	420	505	530	610	655	....	510
400	455	545	575	665	710	....	555
500	515	620	660	765	815	....	630
600	575	690	740	855	910	....	710
700	630	755	815	940	1005	....	780
750	655	785	845	980	1045	....	810
800	680	815	880	1020	1085	....	845
900	730	870	940	....	....	....	905
1000	780	935	1000	1165	1240	....	965
1250	890	1065	1130	....	....	....	....
1500	980	1175	1260	1450	....	....	1215
1750	1070	1280	1370	....	....	....	....
2000	1155	1385	1470	1715	....	....	1405

CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C. 86 F.

C. F.							
40 104	.82	.88	.90	.94	.95	....	....
45 113	.71	.82	.85	.90	.92	....	....
50 122	.58	.75	.80	.87	.89	....	....
55 131	.41	.67	.74	.83	.86	....	....
60 140	....	.58	.67	.79	.83	.91	....
70 158	....	.35	.52	.71	.76	.87	....
75 167	....	....	.43	.66	.72	.86	....
80 176	....	....	.30	.61	.69	.84	....
90 194	....	....	....	.50	.61	.80	....
100 212	....	....	....	....	.51	.77	....
120 248	....	....	....	....	....	.69	....
140 284	....	....	....	....	....	.59	....

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Not More Than Three Conductors in Raceway or Cable

(Based on Room Temperature of 30 C. 86 F.)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) / Thermo-plastic Type T (14–4/0) Type TW (14–4/0)	Rubber Type RH	Paper / Thermo-plastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impregnated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	270	315	335	...
300	240	285	300	345	380	...
350	260	310	325	390	420	...
400	280	335	360	420	450	...
500	320	380	405	470	500	...
600	355	420	455	525	545	...
700	385	460	490	560	600	...
750	400	475	500	580	620	...
800	410	490	515	600	640	...
900	435	520	555	..	...	...
1,000	455	545	585	680	730	...
1,250	495	590	645	...	...	...
1,500	520	625	700	785	...	...
1,750	545	650	735	..	...	...
2,000	560	665	775	840	...	...

CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C. 86 F.

C.	F.						
40	104	.82	.88	.90	.94	.95	...
45	113	.71	.82	.85	.90	.92	...
50	122	.58	.75	.80	.87	.89	...
55	131	.41	.67	.74	.83	.86	...
60	140	...	.58	.67	.79	.83	.91
70	158	...	.35	.52	.71	.76	.87
75	167	...	...	.43	.66	.72	.86
80	176	...	...	.30	.61	.69	.84
90	194	...	...	...	.50	.61	.80
100	212	...	...	...	...	.51	.77
120	248	...	...	...	...	...	.69
140	284	...	...	...	...	...	.59

FULL-LOAD CURRENT*
Direct-Current Motors

HP	115V	230V	550V
½	4.6	2.3	.....
¾	6.6	3.3	1.4
1	8.6	4.3	1.8
1½	12.6	6.3	2.6
2	16.4	8.2	3.4
3	24.	12.	5.0
5	40	20	8.3
7½	58	29	12.0
10	76	38	16.0
15	112	56	23.0
20	148	74	31.
25	184	92	38.
30	220	110	46.
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	148
150		534	220
200		712	295

*These values for full-load current are average for all speeds.

FULL-LOAD CURRENT*
Single-Phase A.C. Motors

HP	115V	230V	440V
1/6	3.2	1.6	
¼	4.6	2.3	
½	7.4	3.7	
¾	10.2	5.1	
1	13.	6.5	
1½	18.4	9.2	
2	24.	12.	
3	34.	17.	
5	56.	28.	
7½	80	40.	21.
10	100.	50.	26.

For full-load currents of 208 and 200-volt motors, increase corresponding 230-volt motor full-load current by 10 and 15 per cent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

Full-Load Current*

Two-Phase A.C. Motors (4-wire)

HP	Induction Type Squirrel-Cage and Wound Rotor Amperes					Synchronous Type †Unity Power Factor Amperes			
	110V	220V	440V	550V	2300V	220V	440V	550V	2300V
½	4	2	1	.8					
¾	4.8	2.4	1.2	1.0					
1	6.4	3.2	1.6	1.3					
1½	8.8	4.4	2.2	1.8					
2	11.2	5.6	2.8	2.2					
3		8	4	3.2					
5		13	7	6					
7½		19	9	8					
10		24	12	10					
15		34	17	14					
20		45	23	18					
25		55	28	22	6	47	24	19	4.7
30		67	34	27	7.5	56	29	23	5.7
40		88	44	35	9	75	37	31	7
50		108	54	43	11	94	47	38	9
60		129	65	52	13	111	56	44	11
75		158	79	63	16	140	70	57	13
100		212	106	85	21	182	93	74	17
125		268	134	108	26	228	114	93	22
150		311	155	124	31		137	110	26
200		415	208	166	41		182	145	35

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the name-plate current rating should be used. Current in common conductor of 2-phase, 3-wire system will be 1.41 times value given.

†For 90 and 80 per cent P. F. the above figures should be multiplied by 1.1 and 1.25 respectively.

Full-Load Current*

Three-Phase A.C. Motors

	Induction Type Squirrel-Cage and Wound Rotor Amperes					Synchronous Type †Unity Power Factor Amperes			
HP	110V	220V	440V	550V	2300V	220V	440V	550V	2300V
½	4	2	1	.8					
¾	5.6	2.8	1.4	1.1					
1	7	3.5	1.8	1.4					
1½	10	5	2.5	2.0					
2	13	6.5	3.3	2.6					
3		9	4.5	4					
5		15	7.5	6					
7½		22	11	9					
10		27	14	11					
15		40	20	16					
20		52	26	21					
25		64	32	26	7	54	27	22	5.4
30		78	39	31	8.5	65	33	26	6.5
40		104	52	41	10.5	86	43	35	8
50		125	63	50	13	108	54	44	10
60		150	75	60	16	128	64	51	12
75		185	93	74	19	161	81	65	15
100		246	123	98	25	211	106	85	20
125		310	155	124	31	264	132	106	25
150		360	180	144	37		158	127	30
200		480	240	192	48		210	168	40

For full-load currents of 208 and 200-volt motors, increase the corresponding 220-volt motor full-load current by 6 and 10 per cent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

†For 90 and 80 per cent P. F. the above figures should be multiplied by 1.1 and 1.25 respectively.

Number of Conductors in Conduit or Tubing

Rubber Covered, Types RF-2, RFH-2, R, RH, RHH, RHW, RW, RH-RW, RU, RUH, and RUW

Thermoplastic, Types TF, T and TW

One to Nine Conductors

Size AWG MCM	Number of Conductors in One Conduit or Tubing								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1 ¼
10	½	¾	¾	¾	1	1	1	1 ¼	1 ¼
8	½	¾	¾	1	1 ¼	1 ¼	1 ¼	1 ½	1 ½
6	½	1	1	1 ¼	1 ½	1 ½	2	2	2
4	½	1 ¼	*1 ¼	1 ½	1 ½	2	2	2	2 ½
3	¾	1 ¼	1 ¼	1 ½	2	2	2	2 ½	2 ½
2	¾	1 ¼	1 ¼	2	2	2	2 ½	2 ½	2 ½
1	¾	1 ½	1 ½	2	2 ½	2 ½	2 ½	3	3
0	1	1 ½	2	2	2 ½	2 ½	3	3	3
00	1	2	2	2 ½	2 ½	3	3	3	3 ½
000	1	2	2	2 ½	3	3	3	3 ½	3 ½
0000	1 ¼	2	2 ½	3	3	3	3 ½	3 ½	4
250	1 ¼	2 ½	2 ½	3	3	3 ½	4	4	5
300	1 ¼	2 ½	2 ½	3	3 ½	4	4	5	5
350	1 ¼	3	3	3 ½	3 ½	4	5	5	5
400	1 ½	3	3	3 ½	4	4	5	5	5
500	1 ½	3	3	3 ½	4	5	5	5	6
600	2	3 ½	3 ½	4	5	5	6	6	6
700	2	3 ½	3 ½	5	5	5	6	6	...
750	2	3 ½	3 ½	5	5	6	6	6	...
800	2	3 ½	4	5	5	6	6	...	...
900	2	4	4	5	6	6	6	...	...
1000	2	4	4	5	6	6	...	...	...
1250	2 ½	5	5	6	6	...	...	...	...
1500	3	5	5	6	...	...	...	...	...
1750	3	5	6	6	...	...	...	...	...
2000	3	6	6	...	...	...	...	...	...

*Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end two No. 4 insulated and one No. 4 bare conductors may be installed in 1-inch conduit or tubing.

Useful Information

To find the circumference of a circle, multiply the diameter by 3.1416.

To find the diameter of a circle, multiply the circumference by .31831.

To find the area of a circle, multiply the square of the diameter by .7854.

The radius of a circle $\times$ 6.283185 = the circumference.

The square of the circumference of a circle $\times$ .07958 = the area.

Half the circumference of a circle $\times$ half its diameter = the area.

The circumference of a circle $\times$ .159155 = the radius.

The square root of the area of a circle $\times$ .56419 = the radius.

The square root of the area of a circle $\times$ 1.12838 = the diameter.

To find the diameter of a circle equal in area to a given square, multiply a side of the square by 1.12838.

To find the side of a square equal in area to a given circle, multiply the diameter by .8862.

To find the side of a square inscribed in a circle, multiply the diameter by .7071.

To find the side of a hexagon inscribed in a circle, multiply the diameter of the circle by .500.

To find the diameter of a circle inscribed in a hexagon, multiply a side of the hexagon by 1.7321.

To find the side of an equilateral triangle inscribed in a circle, multiply the diameter of the circle by .866.

To find the diameter of a circle inscribed in an equilateral triangle, multiply a side of the triangle by .57735.

To find the area of the surface of a ball (sphere), multiply the square of the diameter by 3.1416.

To find the volume of a ball (sphere), multiply the cube of the diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

To find the pressure in pounds per square inch at the base of a column of water, multiply the height of the column in feet by .433.

A gallon of water (U. S. Standard) weighs 8.336 pounds and contains 231 cubic inches. A cubic foot of water contains 7½ gallons, 1728 cubic inches, and weighs 62.425 pounds at a temperature of about 39° F.

These weights change slightly above and below this temperature.

Tables and Data

In accordance with the standard practice approved by the American Standards Association, the ratio 25.4 mm = 1 inch is used for converting millimeters to inches. This factor varies only two millionths of an inch from the more exact factor 25.40005 mm, a difference so small as to be negligible for industrial length measurements.

Metric Measures

The metric unit of length is the meter = 39.37 inches.
The metric unit of weight is the gram = 15.432 grains.
The following prefixes are used for sub-divisions and multiples: Milli = $\frac{1}{1000}$, Centi = $\frac{1}{100}$, Deci = $\frac{1}{10}$, Deca = 10, Hecto = 100, Kilo = 1000, Myria = 10,000.

Metric and English Equivalent Measures

MEASURES OF LENGTH

Metric		*English*
1 meter	=	39.37 inches, or 3.28083 feet, or 1.09361 yards
.3048 meter	=	1 foot
1 centimeter	=	.3937 inch
2.54 centimeters	=	1 inch
1 millimeter	=	.03937 inch, or nearly 1-25 inch
25.4 millimeters	=	1 inch
1 kilometer	=	1093.61 yards, or 0.62137 mile

MEASURES OF WEIGHT

Metric		*English*
1 gram	=	15.432 grains
.0648 gram	=	1 grain
28.35 grams	=	1 ounce avoirdupois
1 kilogram	=	2.2046 pounds
.4536 kilogram	=	1 pound
1 metric ton 1000 kilograms	=	.9842 ton of 2240 pounds 19.68 cwt. 2204.6 pounds
1.016 metric tons 1016 kilograms	=	1 ton of 2240 pounds

MEASURES OF CAPACITY

Metric		*English*
1 liter (= 1 cubic decimeter)	=	61.023 cubic inches .03531 cubic foot .2642 gal. (American) 2.202 lbs. of water at 62° F.
28.317 liters	=	1 cubic foot
3.785 liters	=	1 gallon (American)
4.543 liters	=	1 gallon (Imperial)

English Conversion Table

Length

Inches	×	.0833	= feet
Inches	×	.02778	= yards
Inches	×	.00001578	= miles
Feet	×	.3333	= yards
Feet	×	.0001894	= miles
Yards	×	36.00	= inches
Yards	×	3.00	= feet
Yards	×	.0005681	= miles
Miles	×	63360.00	= inches
Miles	×	5280.00	= feet
Miles	×	1760.00	= yards
Circumference of circle	×	.3188	= diameter
Diameter of circle	×	3.1416	= circumference

Area

Square inches	×	.00694	= square feet
Square inches	×	.0007716	= square yards
Square feet	×	144.00	= square inches
Square feet	×	.11111	= square yards
Square yards	×	1296.00	= square inches
Square yards	×	9.00	= square feet
Dia. of circle squared	×	.7854	= area
Dia. of sphere squared	×	3.1416	= surface

Volume

Cubic inches	×	.0005787	= cubic feet
Cubic inches	×	.00002143	= cubic yards
Cubic inches	×	.004329	= U. S. gallons
Cubic feet	×	1728.00	= cubic inches
Cubic feet	×	.03704	= cubic yards
Cubic feet	×	7.4805	= U. S. gallons
Cubic yards	×	46656.00	= cubic inches
Cubic yards	×	27.00	= cubic feet
Dia. of sphere cubed	×	.5236	= volume

Weight

Grains (avoirdupois)	×	.002286	= ounces
Ounces (avoirdupois)	×	.0625	= pounds
Ounces (avoirdupois)	×	.00003125	= tons
Pounds (avoirdupois)	×	16.00	= ounces
Pounds (avoirdupois)	×	.01	= hundredweight
Pounds (avoirdupois)	×	.0005	= tons
Tons (avoirdupois)	×	32000 00	= ounces
Tons (avoirdupois)	×	2000.00	= pounds

English Conversion Table

Energy			
Horsepower	×	33000.	= ft.-lbs. per min.
B. t. u.	×	778.26	= ft.-lbs.
Ton of refrigeration	×	200.	= B. t. u. per min.
Pressure			
Lbs. per sq. in.	×	2.31	= ft. of water (60°F.)
Ft. of water (60°F.)	×	.433	= lbs. per sq. in.
Ins. of water (60°F.)	×	.0361	= lbs. per sq. in.
Lbs. per sq. in.	×	27.70	= ins. of water (60°F.)
Lbs. per sq. in.	×	2.041	= ins. of Hg. (60°F.)
Ins. of Hg (60°F.)	×	.490	= lbs. per sq. in.
Power			
Horsepower	×	746.	= watts
Watts	×	.001341	= horsepower
Horsepower	×	42.4	= B. t. u. per min.
***Water Factors* (at point of greatest density—39.2°F)**			
Miners inch (of water)	×	8.976	= U. S. gals. per min.
Cubic inches (of water)	×	.57798	= ounces
Cubic inches (of water)	×	.036124	= pounds
Cubic inches (of water)	×	.004329	= U. S. gallons
Cubic inches (of water)	×	.003607	= English gallons
Cubic feet (of water)	×	62.425	= pounds
Cubic feet (of water)	×	.03121	= tons
Cubic feet (of water)	×	7.4805	= U. S. gallons
Cubic feet (of water)	×	6.232	= English gallons
Cubic foot of ice	×	57.2	= pounds
Ounces (of water)	×	1.73	= cubic inches
Pounds (of water)	×	26.68	= cubic inches
Pounds (of water)	×	.01602	= cubic feet
Pounds (of water)	×	.1198	= U. S. gallons
Pounds (of water)	×	.0998	= English gallons
Tons (of water)	×	32.04	= cubic feet
Tons (of water)	×	239.6	= U. S. gallons
Tons (of water)	×	199.6	= English gallons
U. S. gallons	×	231.00	= cubic inches
U. S. gallons	×	.13368	= cubic feet
U. S. gallons	×	8.345	= pounds
U. S. gallons	×	.8327	= English gallons
U. S. gallons	×	3.785	= liters
English gallons (Imperial)	×	277.41	= cubic inches
English gallons (Imperial)	×	.1605	= cubic feet
English gallons (Imperial)	×	10.02	= pounds
English gallons (Imperial)	×	1 201	= U. S. gallons
English gallons (Imperial)	×	4.546	= liters

Metric Conversion Table

Length			
Millimeters	×	.03937	= inches
Millimeters	÷	25.4	= inches
Centimeters	×	.3937	= inches
Centimeters	÷	2.54	= inches
Meters	×	39.37	= inches (Act. Cong.)
Meters	×	3.281	= feet
Meters	×	1.0936	= yards
Kilometers	×	.6214	= miles
Kilometers	÷	1.6093	= miles
Kilometers	×	3280.8	= feet
Area			
Sq. Millimeters	×	.00155	= sq. in.
Sq. Millimeters	÷	645.2	= sq. in.
Sq. Centimeters	×	.155	= sq. in.
Sq. Centimeters	÷	6.452	= sq. in.
Sq. Meters	×	10.764	= sq. ft.
Sq. Kilometers	×	247.1	= acres
Hectares	×	2.471	= acres
Volume			
Cu. Centimeters	÷	16.387	= cu. in.
Cu. Centimeters	÷	3.69	= fl. drs. (U.S.P.)
Cu. Centimeters	÷	29.57	= fl. oz. (U.S.P.)
Cu. Meters	×	35.314	= cu. ft.
Cu. Meters	×	1.308	= cu. yards
Cu. Meters	×	264.2	= gals. (231 cu. in.)
Litres	×	61.023	= cu. in. (Act. Cong.)
Litres	×	33.82	= fl. oz. (U.S.P.)
Litres	×	.2642	= gals. (231 cu. in.)
Litres	÷	3.785	= gals. (231 cu. in.)
Litres	÷	28.317	= cu. ft.
Hectolitres	×	3.531	= cu. ft.
Hectolitres	×	2.838	= bu. (2150.42 cu. in.)
Hectolitres	×	.1308	= cu. yds.
Hectolitres	×	26.42	= gals. (231 cu. in.)
Weight			
Grams	×	15.432	= grains (Act. Cong.)
Grams	÷	981.	= dynes
Grams (water)	÷	29.57	= fl. oz.
Grams	÷	28.35	= oz. avoirdupois
Kilo-grams	×	2.2046	= lbs.

Metric Conversion Table (Cont.)

Weight

Kilo-grams	×	35.27	= oz. avoirdupois
Kilo-grams	×	.0011023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	1.1023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	2204.6	= lbs.

Unit Weight

Grams per cu. cent.	÷	27.68	= lbs. per cu. in.
Kilo per meter	×	.672	= lbs. per ft.
Kilo per cu. meter	×	.06243	= lbs. per cu. ft.
Kilo per Cheval	×	2.235	= lbs. per h. p.
Grams per liter	×	.06243	= lbs. per cu. ft.

Pressure

Kilo-grams per sq. cm.	×	14.223	= lbs. per sq. in.
Kilo-grams per sq. cm.	×	32.843	= ft. of water (60°F.)
Atmospheres (international)	×	14.696	= lbs. per sq. in

Energy

Joule	×	.7376	= ft. lbs.
Kilo-gram meters	×	7.233	= ft. lbs.

Power

Cheval vapeur	×	.9863	= h. p.
Kilo-watts	×	1.341	= h. p.
Watts	÷	746.	= h. p.
Watts	×	.7373	= ft. lbs. per sec

Miscellaneous

Kilogram calorie	×	3.968	= B. t. u.
Standard gravity (Sea level 45° lat.)	÷	980.665	= centimeters per sec. per sec.
Frigories/hr. (French)	÷	3023.9	= Tons refrigeration

The following pages show temperatures on Fahrenheit and Centigrade thermometers.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
—459.4	—273	—21.	—29.4	17.6	—8.	56.	13.3
—436.	—270.	—20.2	—29.	18.	—7.8	57.	13.9
—418.	—260.	—20.	—28.9	19.	—7.2	57.2	14.
—400.	—240.	—19.	—28.3	19.4	—7.	58.	14.4
—382.	—230.	—18.4	—28.	20.	—6.7	59.	15.
—364.	—220.	—18.	—27.8	21.	—6.1	60.	15.6
—346.	—210.	—17.	—27.2	21.2	—6.	60.8	16.
—328.	—200.	—16.6	—27.	22.	—5.6	61.	16.1
—310.	—190.	—16.	—26.7	23.	—5.	62.	16.7
—292.	—180.	—15.	—26.1	24.	—4.4	62.6	17.
—274.	—170.	—14.8	—26.	24.8	—4.	63.	17.2
—256.	—160.	—14.	—25.6	25.	—3.9	64.	17.8
—238.	—150.	—13.	—25.	26.	—3.3	64.4	18.
—220.	—140	—12.	—24.4	26.6	—3.	65.	18.3
—202.	—130.	—11.2	—24.	27.	—2.8	66.	18.9
—184.	—120.	—11.	—23.9	28.	—2.2	66.2	19.
—166.	—110.	—10.	—23.3	28.4	—2.	67.	19.4
—148.	—100.	— 9.4	—23.	29.	—1.7	68.	20.
—139.	— 95.	— 9.	—22.8	30.	—1.1	69.	20.6
—130.	— 90.	— 8.	—22.2	30.2	—1.	69.8	21.
—121.	— 85.	— 7.6	—22.	31.	—0.6	70.	21.1
—112.	— 80.	— 7.	—21.7	32.	0.	71.	21.7
—103.	— 75	— 6.	—21.1	33.	+0.6	71.6	22.
— 94.	— 70.	— 5.8	—21.	33.8	1.	72.	22.2
— 85.	— 65.	— 5.	—20.6	34.	1.1	73.	22.8
— 76.	— 60.	— 4.	—20.	35.	1.7	73.4	23.
— 67.	— 55.	— 3.	—19.4	35.6	2.	74.	23.3
— 58.	— 50.	— 2.2	—19.	36.	2.2	75.	23.9
— 49.	— 45.	— 2.	—18.9	37.	2.8	75.2	24.
— 40.	— 40.	— 1.	—18.3	37.4	3.	76.	24.4
— 39.	— 39.4	— 0.4	—18.	38.	3.3	77.	25.
— 38.2	— 39.	0.	—17.8	39.	3.9	78.	25.6
— 38.	— 38.9	+ 1.	—17.2	39.2	4.	78.8	26.
— 37.	— 38.3	1.4	—17.	40.	4.4	79.	26.1
— 36.4	— 38.	2.	—16.7	41.	5.	80.	26.7
— 36.	— 37.8	3.	—16.1	42.	5.6	80.6	27.
— 35.	— 37.2	3.2	—16.	42.8	6.	81.	27.2
— 34.6	— 37.	4.	—15.6	43.	6.1	82.	27.8
— 34.	— 36.7	5.	—15.	44.	6.7	82.4	28.
— 33.	— 36.1	6.	—14.4	44.6	7.	83.	28.3
— 32.8	— 36.	6.8	—14.	45.	7.2	84.	28.9
— 32.	— 35.6	7.	—13.9	46.	7.8	84.2	29.
— 31.	— 35.	8.	—13.3	46.4	8.	85.	29.4
— 30.	— 34.4	8.6	—13.	47.	8.3	86.	30.
— 29.2	— 34.	9.	—12.8	48.	8.9	87.	30.6
— 29.	— 33.9	10.	—12.2	48.2	9.	87.8	31.
— 28.	— 33.3	10.4	—12.	49.	9.4	88.	31.1
— 27.4	— 33.	11.	—11.7	50.	10.	89.	31.7
— 27.	— 32.8	12.	—11.1	51.	10.6	89.6	32.
— 26.	— 32.2	12.2	—11.	51.8	11.	90.	32.2
— 25.6	— 32.	13.	—10.6	52.	11.1	91.	32.8
— 25.	— 31.7	14.	—10.	53.	11.7	91.4	33.
— 24.	— 31.1	15.	— 9.4	53.6	12.	92.	33.3
— 23.8	— 31.	15.8	— 9.	54.	12.2	93.	33.9
— 23.	— 30.6	16.	— 8.9	55.	12.8	93.2	34.
— 22.	— 30.	17.	— 8.3	55.4	13.	94.	34.4

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
95.	35.	134.	56.7	172.4	78.	211.	99.4
96.	35.6	134.6	57.	173.	78.3	212.	100.
96.8	36.	135.	57.2	174.	78.9	213.	100.6
97.	36.1	136.	57.8	174.2	79.	213.8	101.
98.	36.7	136.4	58.	175.	79.4	214.	101.1
98.6	37.	137.	58.3	176.	80.	215.	101.7
99.	37.2	138.	58.9	177.	80.6	215.6	102.
100.	37.8	138.2	59.	177.8	81.	216.	102.2
100.4	38.	139.	59.4	178.	81.1	217.	102.8
101.	38.3	140.	60.	179.	81.7	217.4	103.
102.	38.9	141.	60.6	179.6	82.	218.	103.3
102.2	39.	141.8	61.	180.	82.2	219.	103.9
103.	39.4	142.	61.1	181.	82.8	219.2	104.
104.	40.	143.	61.7	181.4	83.	220.	104.4
105.	40.6	143.6	62.	182.	83.3	221.	105.
105.8	41.	144.	62.2	183.	83.9	222.	105.6
106.	41.1	145.	62.8	183.2	84.	222.8	106.
107.	41.7	145.4	63.	184.	84.4	223.	106.1
107.6	42.	146.	63.3	185.	85.	224.	106.7
108.	42.2	147.	63.9	186.	85.6	224.6	107.
109.	42.8	147.2	64.	186.8	86.	225.	107.2
109.4	43.	148.	64.4	187.	86.1	226.	107.8
110.	43.3	149.	65.	188.	86.7	226.4	108.
111.	43.9	150.	65.6	188.6	87.	227.	108.3
111.2	44.	150.8	66.	189.	87.2	228.	108.9
112.	44.4	151.	66.1	190.	87.8	228.2	109.
113.	45.	152.	66.7	190.4	88.	229.	109.4
114.	45.6	152.6	67.	191.	88.3	230.	110.
114.8	46.	153.	67.2	192.	88.9	231.	110.6
115.	46.1	154.	67.8	192.2	89.	231.8	111.
116.	46.7	154.4	68.	193.	89.4	232.	111.1
116.6	47.	155.	68.3	194.	90.	233.	111.7
117.	47.2	156.	68.9	195.	90.6	233.6	112.
118.	47.8	156.2	69.	195.8	91.	234.	112.3
118.4	48.	157.	69.4	196.	91.1	235.	112.8
119.	48.3	158.	70.	197.	91.7	235.4	113.
120.	48.9	159.	70.6	197.6	92.	236.	113.3
120.2	49.	159.8	71.	198.	92.2	237.	113.9
121.	49.4	160.	71.1	199.	92.8	237.2	114.
122.	50.	161.	71.7	199.4	93.	238.	114.4
123.	50.6	161.6	72.	200.	93.3	239.	115.
123.8	51.	162.	72.2	201.	93.9	240.	115.6
124.	51.1	163.	72.8	201.2	94.	240.8	116.
125.	51.7	163.4	73.	202.	94.4	241.	116.1
125.6	52.	164.	73.3	203.	95.	242.	116.7
126.	52.2	165.	73.9	204.	95.6	242.6	117.
127.	52.8	165.2	74.	204.8	96.	243.	117.2
127.4	53.	166.	74.4	205.	96.1	244.	117.8
128.	53.3	167.	75.	206.	96.7	244.4	118.
129.	53.9	168.	75.6	206.6	97.	245.	118.3
129.2	54.	168.8	76.	207.	97.2	246.	118.9
130.	54.4	169.	76.1	208.	97.8	246.2	119.
131.	55.	170.	76.7	208.4	98.	247.	119.4
132.	55.6	170.6	77.	209.	98.3	248.	120.
132.8	56.	171.	77.2	210.	98.9	249.	120.6
133.	56.1	172.	77.8	210.2	99.	249.8	121.